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ECONOMIC BOTANY

Devoted to Applied Botany and Plant Utilization

Vol. 2 OCTOBER–DECEMBER, 1948 No. 4

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Seaweed Resources Along the Shores of Great Britain — V. J. Chapman

The Origin of the Cultivated Tomato — J. A. Jenkins

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Figs—Facts and Figures of 1948 — Ira J. Condit

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Utilization Abstracts

By the editor

Chlorophyll. Sugar from Wood. Corn Products.

ECONOMIC BOTANY

Devoted to Applied Botany and Plant Utilization

Founded, managed, edited and published by

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at

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Economic Botany is published quarterly. Subscription price per annual volume everywhere is $5.00; price per single copy is $1.50. Subscriptions and correspondence may be sent to the office of publication, N. Queen St. and McGovern Ave., Lancaster, Pa., or to Economic Botany, The New York Botanical Garden, New York 58, N. Y., and checks should be made payable to Economic Botany. Typescripts should be double-spaced. Photographs will be considered only if of high photographic quality.

Published Quarterly one volume per year, January, April, July and October, at North Queen Street and McGovern Avenue, Lancaster, Pa.

Entered as second-class matter March 12, 1947, at the post office at Lancaster, Pa., under the act of March 3, 1879.

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The Olive Industry of California

In 1947 about 40,000 tons of olives were harvested in the State, to be canned, crushed for oil, shipped fresh, chopped, brine-cured or otherwise prepared.

H. T. HARTMANN[1]

Relation to World Production

California produces about 99% of the olives grown in the United States. Arizona is the only other State having a commercial acreage of olives and has a production ranging from 100 to 600 tons per year. While California accounts for only 0.5% of the total world production, Spain produces 34%, Italy 30%, Greece 12%, Portugal 8%, Tunisia 6% and Turkey 4%. Other Mediterranean countries producing an appreciable quantity of olives are Algeria, Syria and Lebanon, French Morocco, France, Palestine and Yugoslavia. In the Western Hemisphere olives are grown in Argentina, Peru, Chile, Uruguay and Mexico as well as the United States. A small acreage of olives is also found in Australia (6). Although California produces but 0.17% of the world's olive oil, it ranks third in total production of table olives, with 13%. Greece leads with 28%, and Spain is second with 20% (6). The United States imports about 10,000,000 gallons of olives each year. Most of these come from Spain, with smaller quantities from Italy and Greece. Just before World War II, almost 8,000,000 gallons of olive oil were imported annually, supplied mainly by Italy and Spain. This dropped to about 2,000,000 gallons annually during the war years (15).

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Production in the Mediterranean Region (6)

Spain. Spain is by far the leading olive-producing country in the world, the olive being one of its most important crops and ranking second only to cereals in acreage. It is estimated that there are about 140 million bearing olive trees in Spain where over one-half of the world's supply of olive oil is produced. The heaviest plantings are in the south central area surrounding the towns of Jaen, Cordoba, Sevilla and Malaga, although olives are found in most sections of the country except in the northeastern parts. Irrigation of olive orchards is not generally practiced, only about 5% of the acreage being under irrigation. The summers in the important olive-growing sections are hot and dry with an annual rainfall ranging from 16 to 24 inches. The production of olives for oil is the basis of the industry in Spain. Although only about 1.5% of the total acreage in Spain is devoted to the production of table olives, there was an average annual production of this product of about 29,000 tons from 1940–41 to 1944–45. The average production of all olives in Spain during the years 1932 to 1936 was approximately 2,000,000 tons per year.

There are about 25 varieties grown in Spain. The Sevillano and Manzanillo are the main varieties grown for pickling, which is done mostly by the green fermented method. The most important oil varieties are the Picudo, Verdal,

Lechin, Cornezuelo and Zorzalena. Olives in Spain, as in other Mediterranean countries, are attacked by the olive fly, *Dacus oleae*, which causes tremendous damage. It is estimated that losses from this pest amount to about 5% of the value of the average oil yield (3). Spain is not only the greatest producer of olives but also the largest consumer and the largest exporter. About 75% of her production of olive oil is consumed within that country, the remainder being exported, chiefly to the United States and other American countries. She supplies many European countries, and some, such as Italy and France, import large quantities of Spanish olive oil which after further treatment and blending is re-exported to other countries. The per-capita consumption of olive oil in Spain is about 32 pounds per year. In Greece it is 26 pounds, in Italy 11 pounds, and in the United States about 0.2 pound.

Italy. This is the second country of importance in the production of olives. Italy's output of olive oil is about two-thirds that of Spain. The olive is a major crop in Italy, exceeded in value only by cereals, fodder crops and grapes. The areas of production include all portions of the country adjacent to the sea coasts, but the most intense production is in the region surrounding Bari and Lecce in the southeastern section. Here the climate is hot and dry, with mild winters and an average annual rainfall of about 20 inches. Olives are grown in Italy under conditions where the area is devoted exclusively to this crop or, as is more common, in association with other crops, such as almonds, carob, fig, cereals or garden crops. Almost the entire olive production of Italy is used for oil extraction with an average of 220,000 tons of olive oil produced annually. Only about 11,000 tons of olives are processed each year into pickles, while approximately 1,760,000 tons are used for oil. More than 150 varieties of olive are grown in Italy. Some of the principal ones grown for pickling are the Ascolano, Olivo a prugno, St. Agostino and Santa Caterina. Among the important varieties grown for oil are Correggiolo (Frantoio), Leccino (Lechin), Morinello, Coratina, Taggiasca, Pignola, Colombaia, Paesona and Cima di Mola.

Italy is one of the principal importers and exporters of olive oil. Oil is imported from several countries, chiefly Spain, Greece, Turkey and Tunisia. The imported oil is refined and sometimes blended with Italian oils, and exported largely to the South American countries and to the United States.

Greece. This is the third most important country in the production of olives, representing 12% of the world's production. The greater part of the olive oil and pickled olives produced is consumed within the country. Most of the olive oil exported is normally purchased by Italy, with smaller amounts exported to the United States and to Egypt. Greece is one of the chief exporters of table olives, ranking next to Spain in this respect.

The olives are mostly processed by the "Greek style" which consists of dried black olives, salted and in oil. This type of preserved olive is consumed in large quantities as an important food by Latin peoples. Only a relatively small quantity of green olives is exported. Olives are grown in central Greece, Thessaly, Macedonia, the Aegean Islands, the Peloponnesus and Crete. This crop is very important in Greek agriculture, comprising 14% of the agricultural income. Olives are commonly grown in association with cereals, especially barley, cut before maturity as fodder for cattle. Recent reports indicate that there are approximately 50 million trees in Greece producing olives for oil and about 10 million producing olives for pickling.

A large number of varieties are

grown. Some of the important oil varieties are Coronaiki, Mastoides, Myrtolyia, Valanolia, Adramytini and Agouromanakolia. The important varieties grown for pickles are Conservolia and Calamata. Minor varieties are Amygdololia, Carydolia and Carolia.

Portugal. Over 1,250,000 acres of olives are grown in this country at the present time, chiefly for the production of oil. The greater part of this acreage is in the southern half of the central zone. About 9% of the arable land in Portugal is devoted to the olive. It is cultivated alone or in association with other crops, such as fruit trees, grapes or cork oaks. Portugal has a rather limited trade in olive products with foreign countries. Olive oil is imported at times from Spain, mainly for the fish preserves industry. Nearly all the Portuguese olive oil that is exported is sent to Brazil, with some going to the United States. In 1938 about 2,000 tons of preserved olives were exported with 1,700 tons going to Brazil. The remainder was sent mostly to the United States.

The most common variety of olive grown in Portugal is the Galega. Other varieties are the Verdeal, Manzanillo, Cordovil, Sevillano and Redondil.

Tunisia. Tunisia is in fifth place among olive-producing countries of the world. In Tunisian agriculture olive oil is the third most important product, exceeded only by livestock and cereals. Olive culture in this country was at its height during the Roman occupation, but it steadily declined until France took possession of the country in 1881. The European and Tunisian growers have developed the industry markedly in the last 50 years. There are about 600,000 acres planted to olives in Tunisia, with the majority of the acreage in the regions of Sousse, Sfax and Tunis. These regions follow along the eastern coast of the country. Practically the entire olive crop is pressed for oil, with only a very small percentage used for table olives which are consumed within the country. Sixty per cent of the olive trees grown in Tunisia consist of the small-fruited variety Chemlali. Other oil varieties are the Chitoui and Zalmati. The varieties used for pickling are Zarazi, Meski, Barouni, Bidh el Hammam and Tafahi. Large quantities of edible olive oil are exported from Tunisia mainly to France and Italy for further refining and export.

The United States, Norway and Great

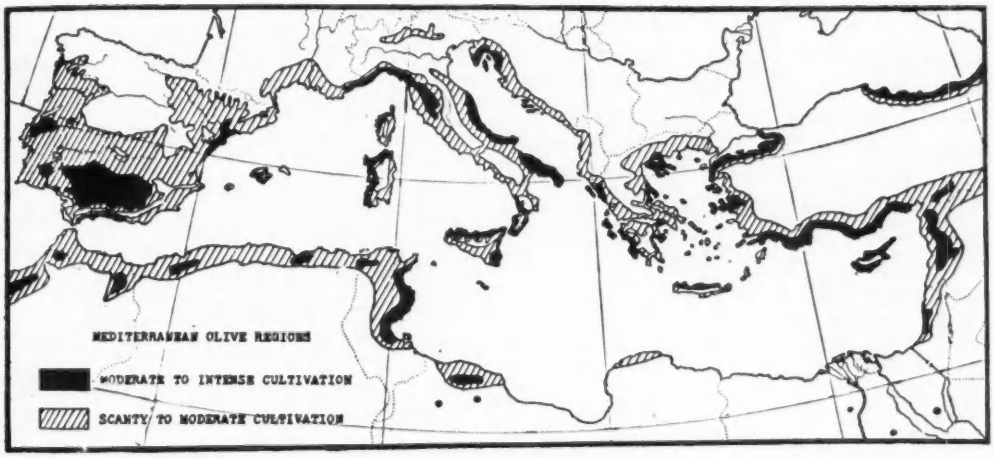


FIG. 1. The olive-producing areas of the Mediterranean region. Ninety-nine per cent of the world's olive crop is produced in the areas shown on this map. Drawing from Bull (3).

Britain also import appreciable quantities of Tunisian olive oil. In 1938 this country exported 38,700 tons of edible olive oil.

Turkey. Olives are the most important tree crop in Turkey, with the western and southwestern provinces adjacent to the Aegean Sea accounting for about 85% of the total production. Official figures give the acreage planted to olives in Turkey as 1,750,000. In 1938 the total olive production was about 185,500 tons. Irrigation of olives is not generally practiced here. Considerable quantities of olive oil are exported, chiefly to Italy for refining and re-export. Small amounts of preserved olives are exported to Roumania, the U. S. S. R. and to Egypt. The principal oil varieties are the Sam, Girit and Ayvalik. The varieties used for pickling are the Hurma, Tırilya and Edremit.

Botany of the Olive

The olive belongs in the genus *Olea* of the family Oleaceae. Other members

FIG. 2. Areas of olive production in California. Tulare county is first, Butte county second, Tehama county third. Each dot represents 100 acres.

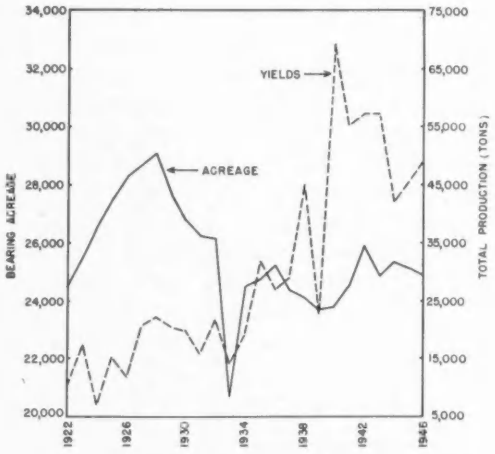


FIG. 3. Fluctuation of bearing acreage and yield of California olives since 1922. The sharp drop in acreage in 1933 was due to a disastrous freeze in December, 1932.

of this family are the ash, forsythia, lilac and privet. All the cultivated varieties of the olive belong in the species *Olea europaea*, although over thirty species of *Olea* have been named (13). The olive is a broad-leaved evergreen tree with opposite leaves. The flowers are borne on a paniculate inflorescence formed during the summer preceding bloom and arising in the axils of the leaves shortly before bloom. The actual floral parts are differentiated, however, only about eight weeks preceding bloom (11). Two types of flowers are produced—perfect and staminate. Pollen production is profuse, and the commonly cultivated varieties are considered to be self-fruitful. The flowers are wind pollinated, although bees visit them to gather pollen. The olive fruit, which is a drupe, turns from deep green to a straw color in October at which time it is harvested for pickling. The color change continues from green to cherry red to jet black, and the fruit attains its highest oil content in December or January. While tremendous numbers of flowers are produced, only a very small percentage of them develop into fruits.

History of California Olives

Olives were first planted in California in 1769, by the Mission padres at Mission San Diego from seeds brought from San Blas, Mexico, by Father Junipero Serra and Don Jose de Galvez (12). The variety which resulted from this early planting was named the Mission and today comprises 53% (4) of the bearing acreage of olives in California. The remaining olive varieties now being grown commercially in California were obtained from Spain, Italy and Tunisia where they existed as standard varieties. The named varieties of olives grown in the world number in the hundreds, and many of these were imported and tested all through the years of development of the industry in California. Private nurserymen and individuals received numerous varieties during the years 1850 to 1900, most of these having long been discarded as of no value. From 1900 to 1934 the Division of Plant Exploration and Introduction of the United States Department of Agriculture imported olive varieties from all over the world. About 45 of these introductions are now in bearing at the U. S. D. A. Plant Introduction Garden at Chico, California. The majority of these are strictly oil varieties and have little value for the present day California olive grower. Recently the California Agricultural Experiment Station resumed importations of varieties from the Mediterranean countries in an effort to obtain varieties noted for their heavy yielding capacities or for their large fruit size.

In 1947, olives ranked eleventh in bearing acreage among California tree fruits, with 25,070 acres. While the bearing acreage of olives in California has not increased appreciably since 1922, the yields per acre have made considerable increases, as shown in Figure 3. The reasons for this are increased age of trees and better cultural care, including more emphasis in recent years on the use of nitrogen fertilizers and the irrigation of orchards through the summer months. Good prices received for olives during the years of the second World War have stimulated planting of new orchards.

Areas of Production in California

Bearing is more regular, yields are highest, and insect and disease control is less of a problem with the olive in the warmer regions of California—the San Joaquin Valley, the Sacramento Valley and portions of the inland area of southern California. Many early plantings of olives were made in the cooler coastal regions, but most of these have been abandoned as unprofitable, chiefly on account of low yields and difficulty in controlling the insect pest, black scale, *Saissetia oleae* (Bern.).

Tulare County leads in the production of olives in California, with 7,376 acres (4) concentrated around the town of Lindsay. Yields are highest in this section also, averaging about three tons per acre. Most of the olive output of the Lindsay section is processed into table olives rather than being pressed for oil. This olive district is on the valley floor at the east side of the San Joaquin Valley near the base of the Sierra Nevada foothills. Most of the olive acreage is on Exeter loam soil. This is a hardpan soil developed on old alluvial fans. The surface soil and subsoil are brown to yellowish-brown and rest on a reddish-brown iron and silica cemented hardpan which is at a depth of two to three feet. This soil absorbs water readily, but deep penetration of moisture is retarded by the hardpan layer. It is considered to be fairly high in available mineral plant nutrients. Immediately surrounding Lindsay are the Honcut sandy loam and the Farwell fine sandy loam soils on which appreciable olive acreage is also

located. These are soils developed on alluvial outwash from the hills and are derived from basic igneous rock. These soils are easy to cultivate and irrigate, are fairly well supplied with plant nutrients, and are not underlain by hardpan.

The portion of Butte County surrounding Oroville is the second area of importance in California production. There are 4,271 acres (4) planted with an appreciable percentage of the crop used for oil extraction. Yields are lower than in Tulare County, averaging about 2½ tons per acre. Most of the olive acreage in this section is on the rolling foothills of the Sierra Nevada mountains. One of the chief soil types on which olives are grown is the Redding gravelly sandy loam. This is a brownish-red soil underlain at a depth of two to three feet by a gravelly and stony hardpan. A considerable olive acreage in this area is also planted on the Aiken clay loam, a brownish-red soil directly overlying bedrock at a depth of 14 to 36 inches. About 600 acres of olives several miles north of Oroville are grown on the stony phase of the Aiken clay loam. Here the soil contains numerous flat, angular stones varying in diameter from three to six inches. This soil is shallow, with bedrock at a depth of 10 to 24 inches.

The area of Tehama County around Corning ranks third in olive production, with 2,780 acres (4). The production of large-sized table olives is emphasized here, since practically the entire acreage is planted to the large-fruited variety, Sevillano, an importation from Seville, Spain. Little oil extraction is done in this section now. The yields average approximately two tons per acre. The olive plantings in this area were first made about 1895 as part of a real estate sub-division of five-, ten- and 20-acre tracts known as the Maywood Colony. Many varieties were planted originally with the idea of producing olive oil, but about 1910 the growers started top-working their trees, mostly to the Sevillano variety. The Corning olive area is on the west side of the Sacramento Valley. A large majority of the olive orchards near Corning is grown on Tehama loam soil which is relatively shallow, about 18 to 24 inches deep. The subsoil below is a rather compact clay or clay loam into which water and roots penetrate very slowly. Some olive orchards are located on a deep gravelly phase of this same soil, which is more permeable to water and roots. Some orchards are grown on a deep, light-textured, very gravelly loam soil of the Maywood series, and the so called "red hill" soils of the Corning series. The Maywood gravelly loam is quite permeable and takes water rapidly. The "red hill" soils are a shallow, gravelly loam of low fertility and are usually somewhat acid. The subsoil is a heavy clay which is very slowly permeable to water penetration. In general, there are no hardpan soils in this area.

About 1,824 acres (4) are planted to olives in Sacramento County in the vicinity of Fair Oaks. Yields are relatively low, about one ton per acre, and disease and insect control are rather difficult in this section. The olive orchards in this area are somewhat scattered and are found on the lower slopes of the foothills. The orchards near Fair Oaks are grown on the Arnold sandy loam soil type which is derived from the weathering of loosely consolidated sedimentary deposits of clay and sand. This soil is light gray to brownish-gray and often attains a depth of six feet or more. It absorbs rainfall readily. Olive orchards in this area are also situated on soils of the San Joaquin series consisting of red or light-red material underlain by hardpan.

Many of the early day olive plantings were made in southern California, principally in San Diego, Riverside and Los

Angeles counties. Due to difficulties in controlling black scale, and the pronounced erratic bearing habit of the olive in these districts, many of the plantings were abandoned, and this section is no longer so important in olive production as it once was. About 4,500 acres (4) of olives are now grown in southern California.

Olive Varieties

Mission. The Mission is the leading variety in acreage in California at the present time. It has the highest oil content of any of the commercially grown varieties, averaging about 24% on a fresh weight basis (9). This variety is liked by processors because it is easy to pickle, and a good, uniform product is generally obtained. The Mission fruit varies from medium to large in size, weighing from four to six grams (9). Its shape is variable, from broadly oval to oval-elongated. The apex half is either rounded, bluntly pointed or with a distinct projection at the end. This variety is losing its popularity with many growers, especially in the Tulare County section, due in part to its tendency toward erratic bearing. In some years the trees fail completely to set a crop; in other years far too many fruits set, with few of them reaching a profitable size. Also, the fruit of this variety matures late, and in years of early frost it is damaged so that it cannot be utilized for the more profitable pickles but must be sold for oil extraction. In addition, the fruit is rather small and does not meet the market demand for the larger sized fruits. The Mission trees have a tendency to grow upright, and older trees become so tall that the harvesting operations are difficult and costly. This variety is not generally favored for new plantings at this time, and much Mission acreage is being grafted to other varieties.

Manzanillo. The Manzanillo came to California from Spain and has a name which means "little apple" in Spanish, referring to the roundish, apple-shaped fruit. This variety ranks second to the Mission in bearing acreage and is now considered by many growers to be the best all-purpose variety available. It is much more regular in its production than any of the commonly grown varieties with the possible exception of the Barouni. The Manzanillo ripens early and is harvested before frost is likely to occur. The fruit is somewhat larger than the Mission, and although its oil content, about 15% to 20% on a fresh weight basis (9), is not so high as that of the Mission, it is high enough to justify using it for oil extraction. It is easily processed and makes an excellent quality pickle. The trees are of a spreading habit of growth rather than upright, which facilitates harvesting operations. The fruit is medium in size and of fairly tough texture. It is uniform in shape, broadly oval or slightly ovoid.

Sevillano. This is also a Spanish variety imported from the famous Seville olive district of Spain. The outstanding feature of this variety is its large sized fruit, the largest grown in California. It will average about 13 grams per fruit on a fresh weight basis (9). While the fruit is large, the pit is also large, which feature is, of course, undesirable. The quality of the processed fruit is not considered to be so high as that of the Mission or Manzanillo, and its oil content is too low to warrant use in oil pressing. This variety is rather difficult to process, and a good deal of care and attention must be given to the fruit during pickling. The Sevillano tends to be rather erratic in its bearing. The trees are easy to harvest due to the large sized fruit and the spreading habit of growth. The premium paid by consumers for large olive fruits has resulted in a considerable acreage being planted to this

variety, especially in the Corning district.

Ascolano. The Ascolano olive was brought to this country from Italy. It is a large-fruited variety, slightly smaller than the Sevillano, but the fruit is more tender and requires careful handling during harvesting and processing. It can be distinguished by its very light green color before maturity, at which time the fruit turns a dark wine color. The oil content is too low for oil pressing; it is best utilized in the production of canned ripe olives.

Barouni. This is a fairly large-fruited variety which was introduced into California in 1905 from Tunisia. It bears heavily and was widely planted for a number of years, especially in the Oroville district. The fruits are difficult to process, however, and the finished product is likely to be woody and tough. An appreciable amount of the crop of this variety is shipped fresh from California to the eastern United States where people of Mediterranean extraction purchase the fruit for home processing. Since the oil content of the fruit is relatively low, it is used almost entirely in the production of table olives.

FIG. 4 (*Left*). Appearance of olive flowers at full bloom. This usually occurs in the first part of May.

FIG. 5 (*Right*). Fruiting habit of the olive. Only a very small percentage of the flowers produced develop into fruits.

Production Problems

The olive has been noted since antiquity for its erratic bearing behavior. Even now the problem is not fully understood, and no satisfactory method is known to induce the trees to set good crops each year. There are marked varietal differences in bearing; the Barouni and Manzanillo, for example, can usually be depended upon to set a good

crop annually. The Mission, Sevillano and Ascolano are quite prone to irregular bearing. Some olive orchards are definitely "alternate bearers", similar to certain apple and plum varieties; that is, they bear only every other year. Many orchards, however, have the peculiarity of setting no fruit, or only a few scattered ones, for several consecutive years, although the bloom is heavy each year. In these cases it has been observed that the flowers which appear are the staminate type and, of course, soon drop. Some physiological condition within the tree reduces the number of perfect flowers differentiated, thereby reducing the resulting crop to an unprofitably low level. The cause of this condition is not known, although it possibly is connected with the nutritive state of the tree at some critical period during flower bud differentiation.

The California olive growers, particularly those in the Tulare County section, are faced with a serious problem in the control of the olive scale, *Parlatoria oleae* (Colvée). This insect attacks the fruit, causing dark purple spots to form on the green surface. These spots remain on the fruit, even after pickling, thus rendering the product unsalable. Such cull fruit could ordinarily be used for oil extraction, but attacks by scale cause a reduction of 20% to 25% in the oil content. The most effective control at present for this pest consists of tent fumigation with heavy dosages of hydrogen cyanide. This is a costly operation and may not be possible in years of low crop returns. Fumigation after the first of March is hazardous due to injury to the developing buds. The Mission variety is most likely to be injured, followed by the Ascolano, Sevillano and Manzanillo.

The most widespread olive insect pest in California is black scale, *Saissetia oleae* (Bern.). It has certain natural controls, chiefly high temperature and various predators and parasites. Nevertheless, many orchards must be sprayed with summer oils during August to keep this scale under control. DDT used experimentally in November after fruit harvest shows promise of good control.

Oleander scale, *Aspidiotus hederae*, is widespread in California olive orchards, especially in the Tulare and Butte County areas. This insect causes damage chiefly by producing green spots on the normally darkening fruit and by causing pitted or deformed fruits to develop. Control is by summer oil sprays in June or July or with heavier oil sprays applied during January or February. Tent fumigation with hydrogen cyanide during the winter months gives the best control.

California olive growers have never had to contend with the worst insect pest of the olive. This is the olive fly, *Dacus oleae*, which is found in all olive-producing countries of the Mediterranean region. The fly, active from May to the end of November, has a series of generations through the season. It lays its eggs in the growing fruit, and, after hatching, the larvae burrow in the fruit, pupate and emerge as adults. In order to avoid as much damage as possible from this insect, which attains high numbers toward the end of the season, the fruits are harvested early, too early to permit their being processed into the black ripe olive. Hence, no appreciable amount of this product is prepared for export; only the green fermented olive, which can be picked early, is produced in quantities. As a result of this situation the California olive grower is considered to have a monopoly of the black ripe olives sold in the United States.

While many importations of olive scions and cuttings from the Mediterranean have been made for over 100 years, this insect has never been introduced into the United States because it

METRIC 1 2 3 4 5 6 7 8 9 10

METRIC 1 2 3 4 5 6 7 8 9 10

lives only on the unprocessed olive fruits, which are not imported.

Two diseases are of importance in California olive orchards. One of these, caused by the fungus *Cycloconium oleaginum*, is generally called "Peacock Spot" because of its resemblance to peacock plumage. The leaves are affected in spots by the fungus which later causes them to turn yellow and drop. Severe defoliation is sometimes found in neglected orchards. Widely spaced, vigorous, well-cared-for orchards generally are not troubled with this disease which can be controlled by thorough spraying with Bordeaux mixture or lime sulfur in November after harvest.

The other olive disease, caused by bacteria, *Bacterium savastanoi*, is called "Olive Knot", and has long been known in California, being first discovered in 1898. The Mission variety is the least susceptible among the common varieties grown in California, while the Sevillano is considered to be one of the most likely to be attacked. As the Sevillano is the predominate variety in the Corning olive section, this disease is very much in evidence there. While the trees are undoubtedly injured by attacks of these bacteria, they will continue to bear good crops for many years in spite of the infection. No really satisfactory control has been found, although Wilson (17) obtained evidence that Bordeaux mixture applied during the winter months is effective in preventing infection. Many growers practice cutting out the galls and disinfecting the cuts and tools with formalin or corrosive sublimate. Openings in the bark, due to natural or artificial causes, are apparently necessary for infection to occur.

Cultural Practices

Propagation. Olives in California are commonly propagated by means of cuttings, either hardwood or softwood. Some commercial nurseries propagate olive trees entirely by softwood cuttings. Cuttings of most of the California olive varieties root fairly readily with the exception of the Sevillano which roots with difficulty unless treated with root-promoting substances. Softwood olive cuttings respond markedly to treatments with indolebutyric acid (8). They are generally prepared in October or November and rooted in sand in the greenhouse with bottom heat and high humidity. By spring the cuttings are sufficiently rooted to be set out in the nursery where they are grown for one or two years before they are ready to be planted in the orchard.

Hardwood cuttings are generally used in propagating olives where greenhouse facilities are not available. They consist of wood one or two years old from one-half to one inch in diameter and 8 to 12 inches long. These are planted in nursery rows in the spring and must be grown for two years before they are ready to set out in the orchard. A variation of this method is to secure sucker plants arising from the base of mature trees. Some of these can be taken with a piece of the old root attached. When these are planted in the nursery row, a suitable tree for planting can be secured after one year's growth. When this method is used, it must be determined that the parent tree was propagated from a cutting rather than grafted on a seedling rootstock; otherwise the desired variety will not be obtained.

FIG. 6 (*Upper*). Fruits of the leading olive varieties grown in California. Left to right—Sevillano, Ascolano, Barouni, Manzanillo, Mission.

FIG. 7 (*Lower*). The most serious insect pest on olives today in California is the Parlatoria or Olive Scale, *Parlatoria oleae* (Colvée). Infested fruits are worthless for canning, and the oil content is reduced about 20 per cent. The scale causes dark spots to appear on the green fruit about harvest time.

A method of propagating olives in California which is of less importance is the grafting of seedlings. These seedlings are generally of the Redding Picholine or Mission variety. They are obtained in some instances by germinating seeds and planting them in the nursery where they are grown for one year before grafting. Olive seeds germinate in several weeks if the hard pit is cracked before planting; otherwise a period of about six months to a year is required. Occasionally seedlings are obtained by pulling up volunteer plants arising from fruits which drop under bearing trees. This is done after heavy winter rains. The seedlings are then grafted to the desired variety by the whip-and-tongue method and grown in the nursery row for one or two years before the trees are ready for sale. This method of propagating is used especially with the Sevillano variety which is difficult to root from cuttings.

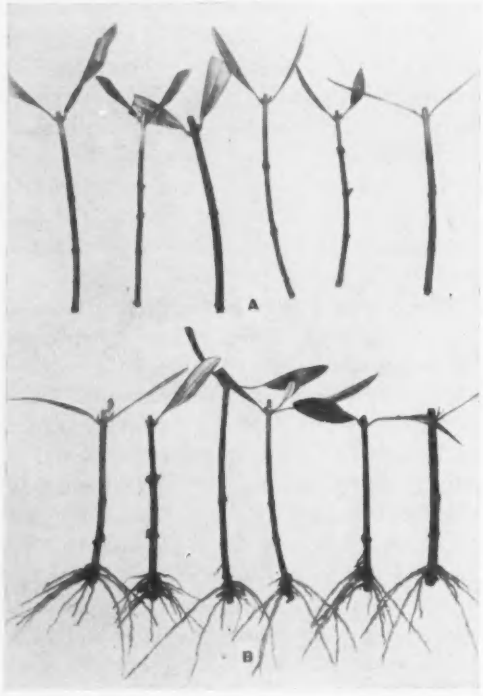


FIG. 8. Effect of a root-promoting substance on Mission olive cuttings after 10 weeks in sand. A, check (no treatment); B, cuttings soaked for 24 hours in 50 parts per million of indolebutyric acid (8).

Topworking of olive trees to change the variety is quite a common procedure. In the early days of the olive industry of California, a great many plantings of small-fruited oil varieties were made. These later proved to be unprofitable and were topworked to one of the present varieties which are grown primarily for the production of processed olives. In topworking mature olive trees, the bark graft method, performed during March or early April, has been found to be the most successful. One or two "nurse" branches are left for the first year to shade the trunk and to reduce the number of suckers arising as a result of the heavy cutting.

There is no information as to the value of various rootstocks for olives. There is also no experimental evidence as to whether olive trees over a period of years are more successful when grown on their own roots from cuttings or when grafted onto seedling rootstocks. There are certainly many successful bearing orchards in California which have been propagated by both methods. An olive rootstock investigation now being started by the California Agricultural Experiment Station will compare olive trees grown on their own roots with those grown on a number of types of rootstocks, including various species of *Olea* as well as vigorous small-fruited oil varieties.

Olive trees in European and North African countries are propagated for the most part by budding the desired varieties to seedling rootstocks either on native wild rootstocks or on seedlings grown for this purpose. Some countries, however, notably Portugal, propagate their trees mainly from cuttings.

Pruning. Little experimental work has been done on methods of pruning

olives in comparison with the detailed procedure that has been worked out for most deciduous fruit species. An investigation on methods of pruning young olive trees conducted by Bioletti (1) and extended by Jacob (10) showed that heavy pruning of young olive trees delayed the age at which they came into bearing. Most commercial olive growers do very little, if any, pruning on young trees until they come into bearing; consequently the majority of mature trees have a great number of primary scaffold branches arising at random from the ground or the trunk. Fortunately olive wood is very strong and very resistant to decay, so that pruning methods which would be disastrous in other fruit tree species will be tolerated successfully by olive trees.

FIG. 9. Inspecting and grading fresh olives before processing. (*Photo courtesy Lindsay Ripe Olive Co.*)

In contrast to the situation regarding pruning of young olive trees, the methods of pruning bearing trees have developed into three more or less distinct types. One group of growers feels that mature trees should be pruned quite severely in the belief that better fruit sizes are thereby obtained, harvesting is made easier and disease control is facilitated. This type of pruning is found principally in the Corning district and to a less extent in the Oroville area.

At the other extreme there are growers who practice little, if any, pruning on bearing trees. Probably the largest group is the third, who prune their trees moderately, removing only dead wood or interfering branches and opening up dense growth to aid in harvesting the fruit and in insect control. Experimental evidence has been obtained by the California Agricultural Extension Serv-

ice in Tulare County that pruning of bearing olive trees reduces the yield about in proportion to the severity of the pruning, without appreciably increasing fruit size.

As the trees of the Mission variety have an upright tendency of growth, and old trees become very tall and difficult to harvest, many growers of this variety keep the upright central branches cut back heavily and encourage the spreading lateral branches.

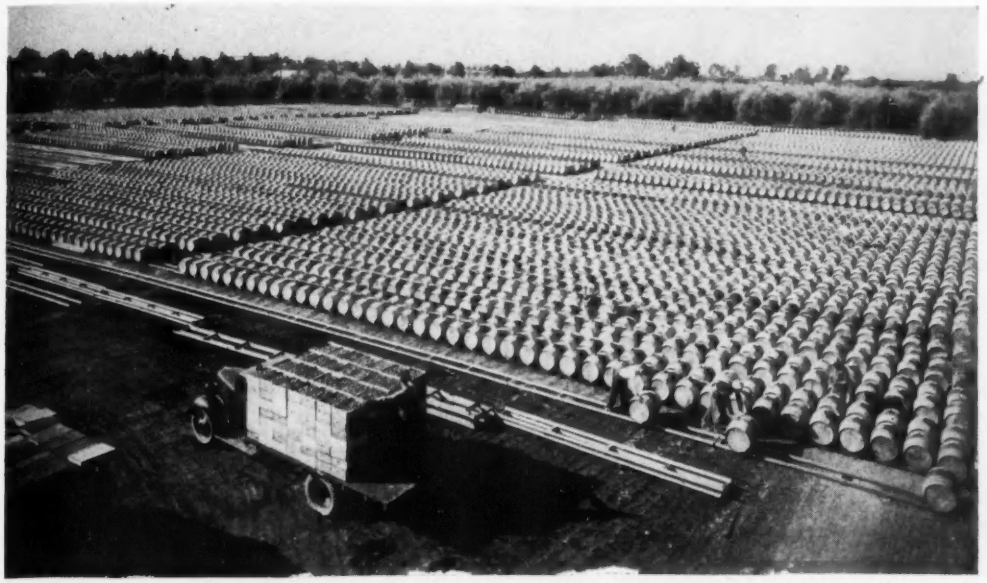
The drastic pruning treatment given olives in some of the Mediterranean areas is probably done in part to reduce leaf area and conserve soil moisture from the winter rains to last through the growing season. California olive orchards, which are grown almost entirely under irrigation, have no need of severe pruning in order to reduce water loss.

Fertilization. The yearly application of nitrogen-containing fertilizers is a very widespread practice among California olive growers. Ammonium sulfate, ammonium nitrate, sodium nitrate and liquid ammonia in the irrigation water are common forms in which nitrogen is added. The use of such fertilizers has become a general practice only in the last ten years and is believed to have contributed heavily to the tremendous increases in yield during that time. Nitrogen-containing fertilizers are applied at varying rates, generally from one-half to two pounds of actual nitrogen per tree. The usual practice is to spread the fertilizer broadcast under the trees during late December, January or February so that winter rains will dissolve the salt and carry it into the root zone by early spring. Animal manures are often used in olive orchards, with the applications made generally in the fall. Heavy use of nitrogen-containing fertilizers sometimes tends to delay the date of fruit maturity in olives as it does in other fruit crops.

In the Wyandotte area of Butte County olive trees have recently shown response to applications of potassium fertilizers by improved appearance of foliage. This is believed to be only a local condition, however, as olives in California are not generally benefited by potash fertilizers.

There is little, if any, evidence that phosphorus is of any benefit to olives in California. There has been no response to applications of any of the other essential elements with the exception of boron (14). One of the soil types in the Butte County olive area is apparently deficient in boron. Olives grown in such soil produce fruits which are shrunken and distorted at the apex end and are termed "monkey-face" fruits. The trees bearing these defective fruits also are observed to have a very much branched and rebranched growth of the twigs due to the death of the growing point with the subsequent growth of lateral buds into shoots. A banded chlorotic condition of the leaves and a dieback of the twigs is also associated with this deficiency disease. Boron-deficient olive trees tend to drop their fruits before maturity, resulting in low yields. Yearly applications of one pound of borax per tree prevent the above-mentioned symptoms in a very striking manner.

Irrigation. Practically all olive orchards in California are irrigated. The average annual rainfall in the olive districts varies from 23 inches at Corning and 27 inches at Oroville to 10 inches at Lindsay. This rainfall comes almost entirely from October to May. The time when irrigation starts in the spring depends upon the amount and duration of the winter rainfall. The frequency of summer applications of water depends upon many factors, such as the weather, soil type, size of trees and density of trees. In general, orchards are irrigated every three to four weeks. The olive is definitely a drought-resistant tree. It will survive and produce fruit without



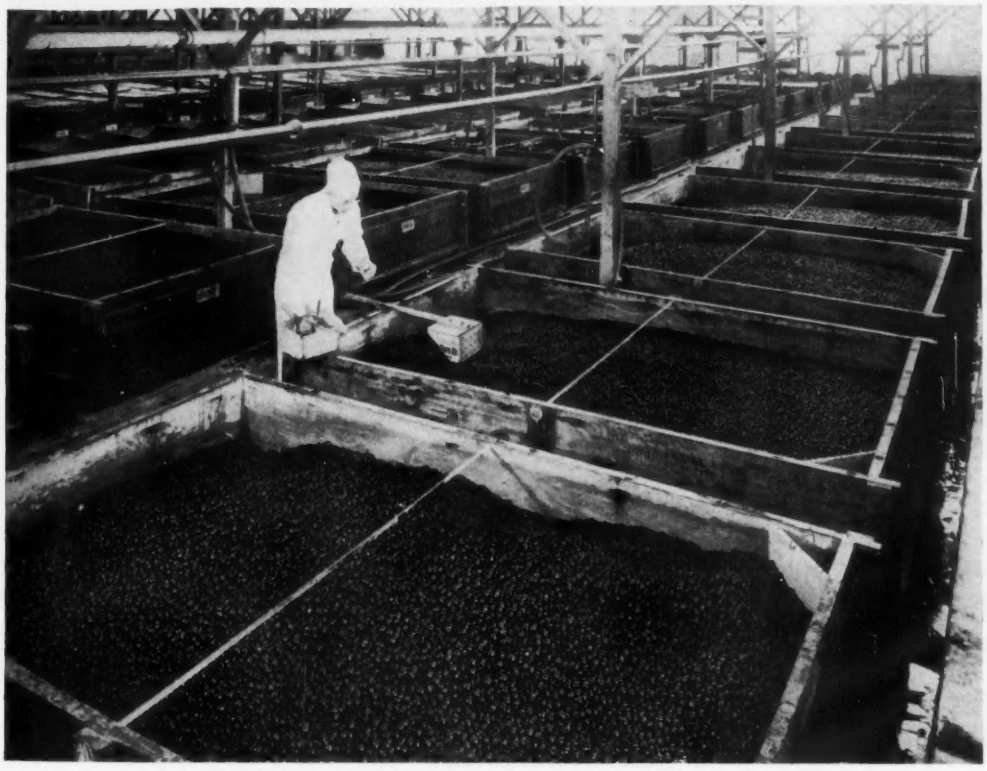
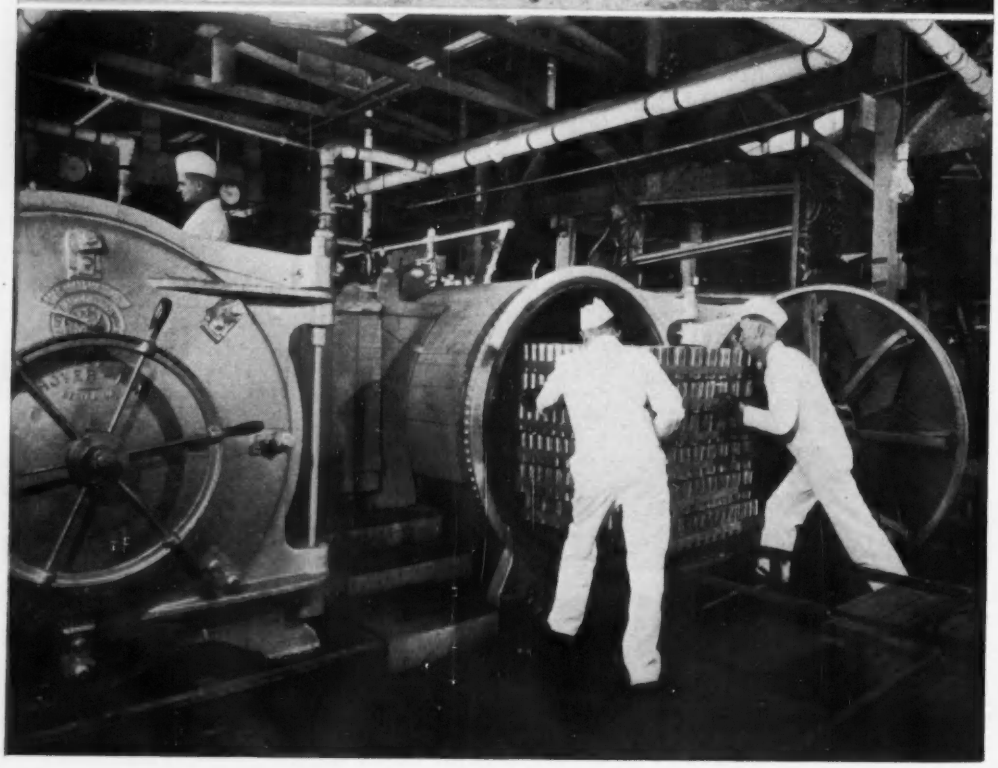


FIG. 10 (*Upper*). Spanish green olives fermenting in barrels. This process continues for 6 to 12 months. (*Photo courtesy Lindsay Ripe Olive Co.*)

FIG. 11 (*Lower*). Black ripe olives during processing. (*Photo courtesy Lindsay Ripe Olive Co.*)



any irrigation, as is amply demonstrated by the thousands of acres of olives grown in the Mediterranean countries without irrigation. The fruits of many, but not all, olive varieties shrivel severely when the soil moisture becomes abnormally low during the growing season. With addition of water to the trees, the fruits readily regain their normal turgor. Lack of sufficient water through the growing season causes the trees to produce abnormally small fruits and short terminal shoot growth which in turn causes low yields due to the reduced bearing surface. The sources of irrigation water in California are deep wells or streams arising in the Sierra Nevada mountains.

Harvesting. The olive-harvesting season in California for fruits which are to be made into pickles usually begins about the first of October and lasts for six weeks. Olives which are to be utilized for green pickles are harvested when they attain the "straw color" stage. Those to be processed into black ripe olives are also harvested when they reach this stage and are generally acceptable also when they attain a cherry-red color. After the olive fruits become black, they can be used only for oil extraction or for pickling by the Greek style, salt-cure process or the Sicilian style process. Fresh olive fruits are very susceptible to bruising and are picked by hand to avoid injury. If olives are to be used for pickling, the harvesting must be completed before frost occurs. Frost damage results in shrivelled fruit that can be utilized only for oil extraction. If the fruit is to be used in the production of olive oil, it is generally left on the tree until mid-December at which time harvesting starts and continues through February. The oil content gradually increases in the olive fruit through the fall and winter months, which justifies the delay in harvesting. The care given olive fruits harvested for pickles is not usually accorded those destined for oil extraction. While some growers insist that the fruit be picked by hand, much of it is removed by beating the limbs with poles until the fruit drops to the ground or onto canvas sheets where it is picked up.

Processing

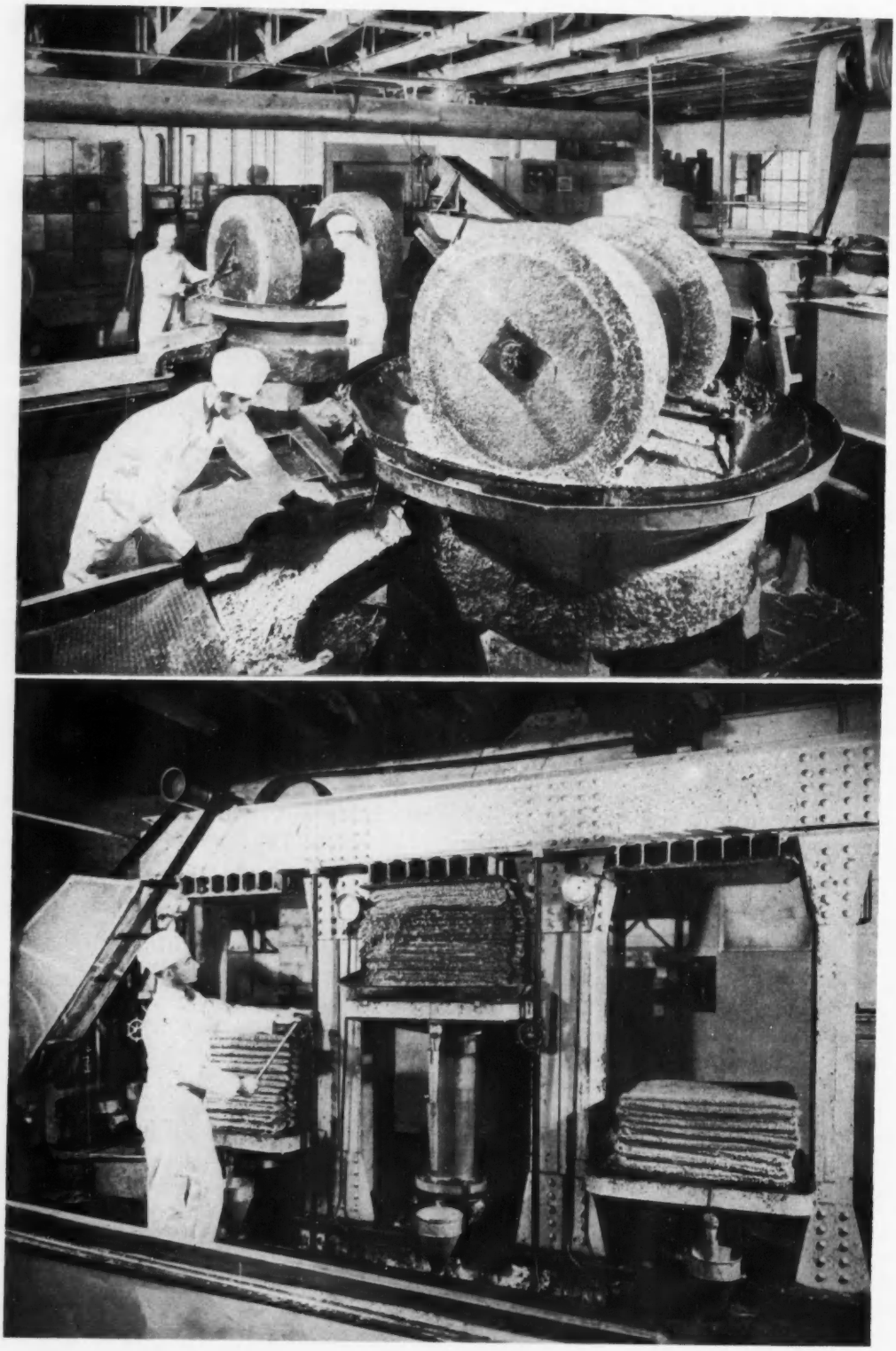
Pickling. As anyone knows who has attempted to eat an olive directly from the tree, they are intensely bitter. This is due to the presence of a bitter glucoside, oleuropein. During processing this glucoside can be neutralized by several methods, but it is chiefly done by treatment with sodium hydroxide.

1. *Black ripe olives.* In the black ripe processing method, the olives are usually stored in a 5% to 9% salt solution for several months immediately after picking, where they undergo a lactic fermentation. After that, they are treated five or six times with dilute sodium hydroxide. Between treatments they are exposed to air for 24 to 48 hours which permits oxidation of orthodihydroxy compounds in the fruit, resulting in the black color of the finished product. The sodium hydroxide is removed by soaking in water which is changed three or four times daily. Following this, the fruits are treated with dilute brine for two to five days and are then canned in dilute brine, after which they are sterilized for 60 minutes at 240° F. under State Board of Health inspection (7).

2. *Green ripe olives.* Fruits processed by this method are pickled immediately after being taken from the tree without undergoing the preliminary lac-

FIG. 12 (*Upper*). Olive bottling machinery. (*Photo courtesy B. E. Glick and Sons, Corning, Cal.*)

FIG. 13 (*Lower*). Canned olives being sterilized at 240° F. for 60 minutes. (*Photo courtesy Lindsay Ripe Olive Co.*)



tic fermentation. They are given one or two treatments with dilute sodium hydroxide but are not exposed to the air so that they do not develop the black color. The fruits are then washed, canned and sterilized as described for the black ripe product. This is a relatively new process and is increasing rapidly in popularity (7).

3. *Spanish style green olives.* This product is the well known green olive which is imported in large quantities from Spain and other Mediterranean countries. It is also an important product of California. The Sevillano and Manzanillo varieties are usually used for this process in California.

The olives are picked in the fall when they attain a light green to straw color. They are immediately placed in a dilute sodium hydroxide solution, with the treatment continuing until the lye has penetrated about three-fourths of the distance to the pit. The lye solution is then removed and replaced with several changes of water to wash the lye from the fruit. During treatment and washing, undue exposure to air is avoided, as this results in an undesirable darkening of the fruit.

The fruit is then placed in 50-gallon oak barrels and kept there for from six to 12 months to undergo lactic fermentation. During this treatment, fruits are kept in a 6% to 8% salt solution, and sugar is added after several weeks to maintain the fermentation process. Following this treatment the olives are packed in glass containers and may or may not be pasteurized (16).

4. *Greek style olives.* Mission and Manzanillo olives are used, harvested after they become jet black. They are stratified in bins with rock salt at the rate of one pound of salt to two pounds of olives and are mixed well by shovelling every two or three days. The treatment with salt removes most of the bitterness, and the fruits also become shrivelled due to plasmolysis by the salt. The fruits are then covered with a thin coating of olive oil and are barreled or boxed for shipment to the eastern States where they are purchased by persons of Mediterranean descent.

Olive Oil. The pressing of oil from olives is of secondary importance in California, the industry being based primarily on the production of olives for pickles. This is just the reverse of the situation in the Mediterranean countries where the production of olive oil is of prime importance. No olive varieties are grown exclusively for oil in California. The oil that is produced results mostly from undersized or cull fruits of the Mission and Manzanillo varieties. California produces but a small percentage of the olive oil consumed in the United States. During the period 1935–1939, the average annual consumption of olive oil in the U. S. was 8,491,000 gallons. Of this, 7,915,000 gallons were imported and 575,000 gallons were produced in California (15). The season for harvesting olives for oil extends from about mid-December to the last of February. The fruit is picked only after it has turned completely black and is at full maturity. After the fruit is harvested, it is either stored in brine, as is done when the fruit is to be used for pickles, or kept for a few days in lug boxes stacked in a cool location. The fruit is sometimes harvested faster than the olive oil factories can extract the oil, thus necessitating an undesirable storage period.

The fruit is washed by sprays of water before crushing, to remove soil and

FIG. 14 (*Upper*). Olives being crushed at an olive oil mill. The revolving concrete wheels grind the olives and liberate the oil. (*Photo courtesy Lindsay Ripe Olive Co.*)

FIG. 15 (*Lower*). Hydraulic pressing of crushed olives which removes the oil and water. (*Photo courtesy Lindsay Ripe Olive Co.*)

leaves, or it is subjected to a suction fan to remove leaves. The fruit is then coarsely crushed in various types of grinders, after which it is collected in press cloths. These are heavy, folded cloths which hold the fruit in a layer about three inches deep. The cloths are placed in layers between woven metal or heavy wooden racks. Pressure is applied, usually by a hydraulic press, at about 500 to 1,000 pounds per square inch. This pressing extracts most of the juice from the fruit and a small proportion of the oil. This oil, called "virgin" oil, is considered to be of higher quality than that resulting from subsequent pressings and is sometimes kept separate.

In some factories the pomace from the first pressing is again ground, much finer than the first grinding, and pressed once more at about 4,000 pounds per square inch. This second pressing extracts most of the oil which is then pumped to settling tanks. Formerly the olive oil was separated from the juice in large settling tanks of 300- to 800-gallon capacity. In most places the juice and oil are now separated continuously by a centrifugal clarifier.

The oil is washed with warm water by various methods of spraying the oil or water into the other. This removes the bitterness from the oil. Fresh olive oil is not pleasing to the taste, and it is aged a short time before bottling or canning. This is done in California in galvanized iron or tin tanks holding about 1,000 gallons. Following this, the oil may be filtered through folded filter paper which produces a brilliantly clear oil ready for bottling. Most plants now filter the oil through diatomaceous earth either in a gravity filter or under pressure. Activated charcoal is sometimes added prior to filtering to remove excess chlorophyll from the oil.

Olive Pomace. The cake which is left after the grinding and pressing still contains 9% to 10% of oil. This can be extracted almost entirely by chemical solvents, such as a special gasoline or carbon tetrachloride. Much of this oil is refined and blended with virgin olive oil, while some is used for the manufacture of soap. Chemical extraction of oil from the "press cake" is more widely practiced in the Mediterranean countries than in California, although the practice is becoming much more common here. The pomace may also be used for boiler fuel or is sometimes spread in the orchard to add humus, although it has very little value as a fertilizer.

Economic Status

The larger sized pickled California olives are much in demand, as indicated by the premium paid for these sizes. The prices paid to growers per ton for graded Sevillano olives at Corning in 1946 were as follows, together with the average number of fruits per pound in the various size grades: Super-colossal (32 fruits per pound), $800; Colossal (36 to 40 fruits per pound), $750; Jumbo (46 to 50 fruits per pound), $650; Giant (53 to 60 fruits per pound), $550; Mammoth (70 fruits per pound), $420; Extra large (82 fruits per pound), $320; Large (98 fruits per pound), $225; Medium (113 fruits per pound), $200; and Standard (135 fruits per pound), $150. These prices were the highest ever received by growers in the history of the California olive industry. The financial return to growers for the 1947 crop was less than half of that received in 1946. A report (2) covering the 28 years between 1918 and 1947 shows the following: *a*) the average return per ton dropped from $131.60 in 1919 to $32 in 1932 and rose to $374 in 1946; *b*) total production rose from 9,000 tons in 1919 to 69,000 in 1940, and fell to 48,000 in 1946; *c*) in 1946, 27,500 tons were canned, 14,300 tons were crushed for oil, 100 tons were shipped fresh,

and 5,900 tons went into other uses including Spanish, Greek and Sicilian style preparations, chopped olives, brine-cured olives and 200 tons for home use.

Most California olives are purchased, processed and marketed by independent concerns located in the chief olive-producing regions. Several cooperatives have been formed to process and market the fruit grown by the members. The California Olive Association, with headquarters in San Francisco, was organized in 1920 to promote the interests of the ripe olive industry. It is a trade association of ripe olive canners and does no marketing.

It is estimated that one-half of the black ripe olives produced in California are consumed in California, Oregon and Washington. In the remainder of the United States the green pickled olives are consumed in greater quantities than the black ripe olive. Some individuals believe that there is opportunity for considerable expansion of the California olive industry if the people throughout the Middle West and East could be induced to purchase the black ripe olive at the same rate that it is used in the West.

An increase in consumer demand for olives was felt during the war years, and an advertising and trade promotion campaign now being inaugurated by the California olive industry will probably enlarge this demand.

During the past ten years the yield per acre of olives in California has increased markedly due largely to better cultural care and increased age of trees. It is likely that this increase in annual production will be maintained, especially if good prices are received by growers. The high returns from olive orchards during the war years are not expected to continue, but it is felt that heavy-yielding orchards will show a profit for many years. Imports of olive oil from the Mediterranean area are expected to increase considerably during 1948. This is due to a bumper 1947–48 olive crop reported from Italy, Spain, Greece, Portugal and Turkey. This, together with the recent devaluation of the Italian lira and Italy's great need for dollars, will mean considerably increased imports of Italian olive oil during 1948. Olive oil production in Italy this season is expected to reach 275,000 tons, as compared with a prewar average of 220,000 tons. The United States Department of Agriculture believes this will satisfy the Italian domestic demand and leave 55,000 tons for export. The output of olive oil in the entire Mediterranean area is expected to reach 1.1 million tons, as compared with 800,000 tons in 1946–47. It is estimated that this will result in an exportable surplus of over 160,000 tons, which is twice the olive oil consumption in the United States. It is expected that Italian exports will supply most of the United States needs for olive oil in 1948. Average American imports of olive oil from 1930 to 1940 were 30,000 to 35,000 tons a year. During the war most shipments were shut off. From 1941 to 1946 imports averaged less than 4,000 tons a year (5).

The tremendous competition from Mediterranean olive oil does not lead to much optimism concerning the profitable production of olive oil in California. Most California olive interests believe the future of the industry here lies in the development of the black ripe olive trade which, so far, in the U. S. markets, has practically been an exclusive California product.

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Utilization Abstract

Chlorophyll. Chlorophyll, extracted from green plants, has been placed on the market by only a few manufacturers, and its use so far has been limited to the coloring of soap and as a mouthwash, a vegetable dye, a deodorizer, a coloring for toothpaste and chewing gum, or as a salve ingredient. The reason is that as yet extracted chlorophyll identical with chlorophyll in the living cell has not been obtained; "the chlorophyll produced today through the use of organic and inorganic reagents is only the pigment component of the physiological chlorophyll of the plant cell. Even the molecule of this extracted pigment component is changed with respect to its original chemical structure as a result of the present extraction methods".

The authors of this article, however, report having been able to produce biologically active, unaltered, stable chlorophyll. They say in conclusion:

"That physiological chlorophyll acts as a catalyst in the human system and has effect on the metabolism—and some pathological conditions, such as high blood pressure—was indicated by clinical results obtained by myself and other physicians. Conclusions, however, as to the last phase, must await more extensive clinical research.

"However, we firmly believe that physiological Chlorophyll, which is the most powerful catalyst in the world if administered either orally or intravenously to human beings, will act as oxidation catalyst in metabolic processes of the human body. This is of utmost importance especially for aging organisms, since pathological changes, such as arteriosclerosis, diabetes, obesity, etc., are due to the slowing down of the rate of oxidation in the cell. Chlorophyll, the life giving substance, is probably the answer to the prayer for prolonging the useful span of life". (*Sophia Berkman* and *Boris Berkman, Chemurgic Digest* 7 (4): 8. 1948).

Seaweed Resources Along the Shores of Great Britain

Extraction of alginates from brown algae and utilization of them in the manufacture of thread in Great Britain during World War II led to a survey of seaweed resources along the coast of Great Britain which revealed a supply of over 2,000,000 tons of bottomweed and rockweed in those waters, especially around Scotland.

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Introduction

DURING war sources of raw material become important, and surveys may be instituted to ascertain the supplies available. Investigations of this nature may also be of scientific importance, and the present report is devoted to one such survey conducted during World War II. It concerns certain brown seaweeds around the shores of Great Britain which were utilized as sources of alginates, particularly in the form of threads, during the war. Although future investigations, using more highly developed techniques, may improve upon the accuracy of this survey, it is considered, in view of the wide field covered, that our results justify publication.

Previous Surveys

So far as can be ascertained, the only previous detailed studies of algal resources anywhere were those by Cameron *et al.* (2, 3) and by Pentegov (8). The former described the giant kelp beds of the Pacific Coast of North America by charting the beds from small vessels as they sailed round them. A similar method was employed by the latter who studied the quantity of seaweed on the eastern shore of Siberia. At the time of the British survey, the principal subject of this article, a similar investigation was instituted in New Zealand (9) where the beds of giant kelp (*Macrocystis*) were charted by means of small boats. In the British survey it was found at the outset that charting by boat alone would not be sufficient because the algae do not float at all times on the surface of the water, and additional methods had therefore to be evolved. The British survey also differed from the earlier ones in that inter-tidal weed was estimated as well as that in the sublittoral beds.

Species of Seaweed Involved

The principal species involved in this survey of 1942 could be divided into two broad categories: rockweed and bottomweed. The first group included the common littoral species—*Ascophyllum nodosum, Fucus vesiculosus, F. serratus*—whilst the second group principally comprised *Laminaria digitata, L. cloustoni* and *L. saccharina*. Apart from a survey of the beds of living weed, an attempt was also made to estimate the amount of cast weed annually thrown up on some of the beaches because this cast can be used commercially. The figures for cast weed are necessarily very approximate, but they are worthy of inclusion because of the relation they bear to the adjacent beds. Two types of *Laminaria* cast can be distinguished: the

winter cast, composed of old stems with some frond attached, and the 'May leaf', composed of the remnants of the old fronds after they have been sloughed off in the spring by the developing new frond.

Laminaria digitata and *L. cloustoni* are to be found commonly only in areas where the substrate is composed of solid rock or large boulders. Where the stones are small both species will grow, but after they have reached a certain size they offer too much resistance to the current, and plant plus stone is swept away. *L. saccharina*, in addition to growing on solid rock, grows attached to small stones, either bare or covered by sand. It is probable that, because of its form, this species offers less resistance to currents than the other two species, but this is a matter that requires further study.

The Survey

The first part of the survey consisted of a preliminary investigation of the coastline from Swanage in Dorset, westwards to Lands End, and thence up the west coast of England and Scotland, across the north coast of Scotland and finally down the east coast to Bridlington in Yorkshire. The purpose of this survey was to locate those areas where there were large beds of bottom or rockweed, with a view to a more detailed survey later. The figures obtained on the first occasion are approximations and hence will not be discussed further. Those interested will find them reported in the special monograph (5). The only estimates of cast weed were obtained during this preliminary survey and will be considered later. The most accurate information about amounts of cast weed was obtained from borough surveyors of seaside resorts who often had to remove it; less accurate information was garnered from harbour masters, coastguards, fishery officers and farmers. These persons were not usually accustomed to thinking of castweed in terms of weight, and it was found necessary to obtain the information expressed in terms of cartloads, and then, after ascertaining the capacity of the local carts, to convert the data into tons.

Methods Employed

(*a*). Boat and grapnel. This method was rarely used alone but usually in conjunction with another, so that its principal value lay in providing direct confirmation of the interpretation. The position of the boat at each grapnel haul was established by means of a box sextant. Experiments with different types of grapnel have been described elsewhere (4).

(*b*). Echo-sounder. The apparatus was attached to a small launch (4), and under certain conditions it provided quite a satisfactory record. Since the records fade after a time, especially if exposed to light, they require to be interpreted at once. The sea-weed bed was usually represented on the chart by a dense fuzz with numerous irregular sharp peaks. For further details of interpretation reference should be made to Chapman (4). When employed in conjunction with confirmatory grapnel hauls, and under favourable conditions (*e.g.*, distinctive type of fuzz), this method is probably at least 90% reliable in determining the limits of beds. It is highly desirable, however, that further investigation into the reliability of this method be undertaken.*

(*c*). In shallow water and with bright sunlight observation from the bow of the boat, or from the top of the cabin, proved highly efficient.

(*d*). Aerial photography. This is the most successful method of surveying seaweed beds, and it is particularly useful in plotting beds that extend down to

* Further experimental work throws doubt upon the reliability of this method.

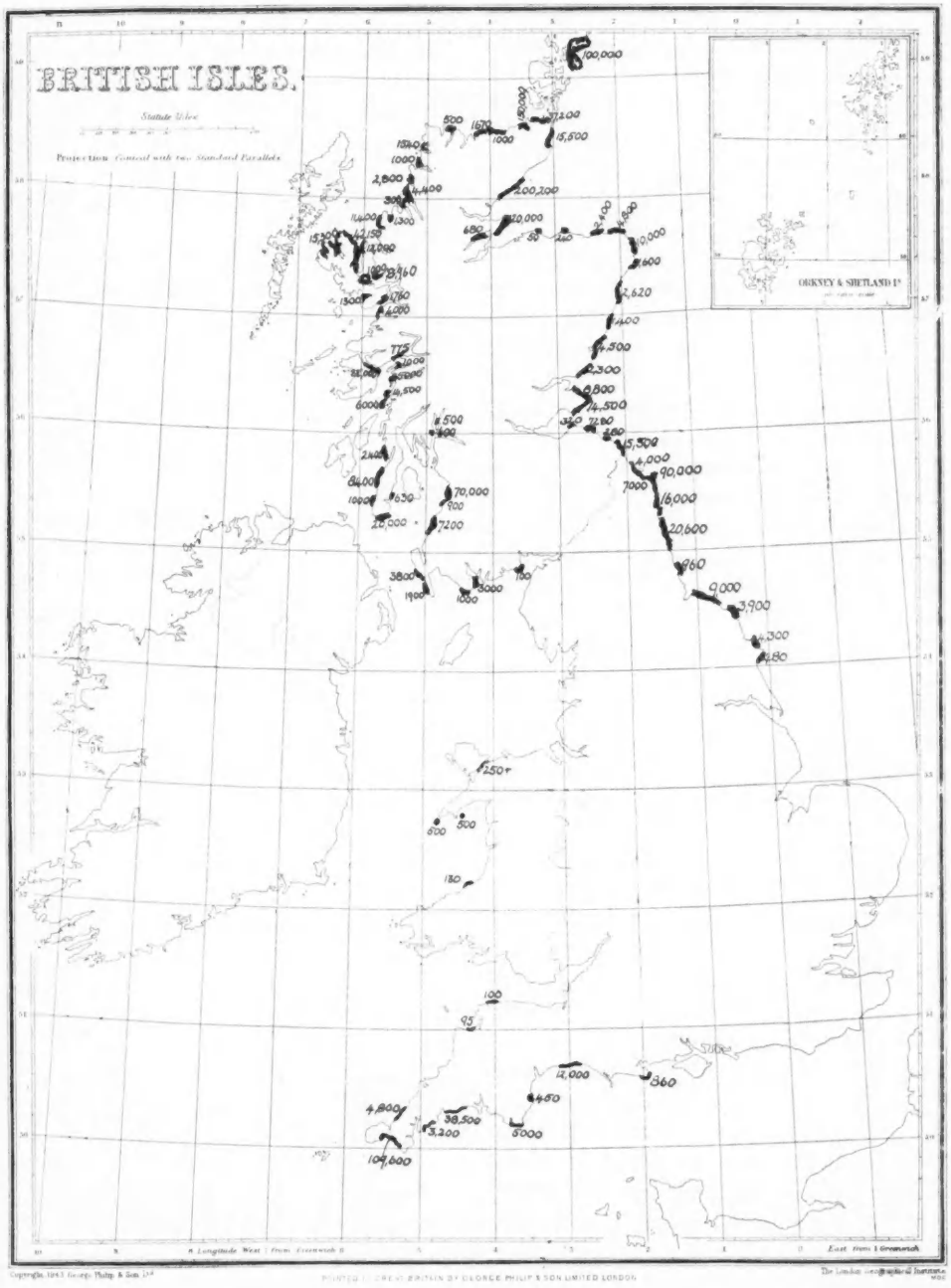

FIG. 1. Map of the British Isles showing the distribution and estimated annual production of bottomweed (*Laminaria digitata, L. cloustoni, L. saccharina*) along the coast of Great Britain, as revealed by a superficial survey conducted in 1942. (This and the other two figures are reproduced here with the permission of the Controller of His Britannic Majesty's Stationery Office, British Crown copyright reserved.)

depths of five to six fathoms. When the seaweed descended deeper the echo-sounder and grapnel had to be employed in order to establish the lower limits. Oblique and vertical photographs were taken, and although, on theoretical grounds, the latter should be more satisfactory, very often the climatic conditions were such that the oblique photographs yielded more information. In interpreting the photographs care has to be taken not to confuse cloud shadows with the beds, and it is also useless to attempt photography if the sea is rough. For further details about the conditions under which air photographs should be obtained and the methods of plotting them, consult Chapman (4).

In areas with sand patches that throw the beds into sharp relief, air photography is 100% efficient for mapping and providing the percentage cover. Where there is no sand the interpretation is rather more difficult and the accuracy is reduced. Under normal conditions a combination of air photography, echo-sounder and grapnel provides a sufficiently accurate means of plotting and estimating seaweed beds. Employment of a diver would increase the accuracy in those cases where beds descend below six fathoms, and would materially increase the accuracy of the tonnage calculations because sample areas could then be cut and weighed.

(*e*). Rockweed. This was calculated by walking along every portion of the coast and estimating the weight of weed. The eye of the observer was trained by periodically cutting sample areas of the different weeds and weighing them. So far as possible one observer undertook all the rockweed estimations, because in this way the personal error was reduced. More recently it has been shown that accurate surveys of rockweed can also be carried out by means of air photography (11).

Tonnage Calculations

In the case of rockweed this was based upon the method described above. *Ascophyllum* varied from three to 30 lbs. or more per sq. yard, and any weight over 20 lbs. represented good cover. The rockweed species possess a well marked growing season, and it is probable that weights recorded in the same area between July and September would be much greater than those in January and February.

Bottom weed is very difficult to estimate because of the difficulties involved in cutting sample areas. *Laminaria cloustoni* is rarely exposed and usually occurs in water too deep for wading. Sample areas (one sq. yd.) of *L. digitata* yielded weights ranging from 12 to 33 lbs., though where there is a strong current greater weights have been recorded. The average weight for *L. digitata* lay between 15 and 20 lbs. per sq. yd., and in making calculations the lower figure was adopted in order not to overestimate. In the case of *L. cloustoni* individual plants were weighed (half to two lbs.), and assuming an average density equivalent to that of *L. digitata* (16 plants per sq. yd.), beds of *L. cloustoni* should range from 16 to 32 lbs. per sq. yd. In order not to over-estimate, and to allow for discrepancies in cover and irregularities in growth, the following standards were adopted: extremely dense, 20 lbs.; very dense, 15 lbs.; dense, 12 lbs.; moderate, 6 lbs.; thin, three lbs.; very thin, one lb. per sq. yd. Deductions were also made for mixed beds or where the plants were known to be small (*e.g.*, Helmsdale). *L. saccharina* is a more difficult plant to estimate for weight, but unless known to be very dense the beds were calculated as being three lbs. or one lb. per sq. yd., depending on density and cover.

Accuracy of Surveys

In the case of bottom weed it has been

indicated that the accuracy of the results depends on the combination of methods employed. The probable error for individual methods is estimated as follows:

(*a*). Grapnel alone. Information very sketchy; cover unknown, ± at least 60%, depending on nature of cover.

(*b*). Grapnel and echo-sounder. Outer edge moderately well-defined; cover incompletely known, ± 40%.

(*c*). Grapnel, echo-sounder and air photographs. Cover and outline well-defined, ± 10–20%.

(*d*). Grapnel and air photographs. Outer edge ill-defined, ± 30%.

Using the above as a basis the probable error in bottom weed estimation for each of the areas studied is given in the following table:

TABLE 1

Area	*Methods*	*Probable error* (% of total)
Girvan	Grapnel and echo-sounder (thorough)	± 35%
Hebrides	Grapnel and air photos (poor)	− 20% to + 50%
Orkneys	Grapnel, echo-sounder and air photos (good)	± 12%
Helmsdale	Grapnel and echo-sounder (fair)	± 40%
Balintore	Grapnel, echo-sounder and air photos (good)	± 20%
Fifeshire	Grapnel and air photos (good)	± 25%
Berwick	Grapnel (thorough)	− 50% to + 20%

In the case of rockweed improved accuracy could be obtained by means of air photographs and by sampling strips instead of square yards. In any event, until the seasonal variation in weight has been established for each species, the values for rockweed cannot have the accuracy of some of the bottom weed figures.

Areas Surveyed

A. Girvan (Ayr to Loch Ryan, around the Mull of Galloway, Luce Bay and on to Garlieston). This was the first area to be surveyed in detail, and only the grapnel and echo-sounder were employed. In Ayr Bay bottomweed rarely extended below three fathoms, and over the major portion *Laminaria saccharina* was the dominant species. In adjacent Bracken Bay, where there was a high proportion of *L. cloustoni*, the plants did not descend below four and a half fathoms. Farther south bottomweed did descend to five fathoms, but over the whole of the area the plants were relatively small. There are several possible explanations of this phenomenon:

(*a*). The rivers running into the Firth of Clyde carry sufficient silt to restrict the depth by limiting light penetration to which the algae can descend. This suggestion could be checked by comparative light-absorption measurements. On the other hand, the light factor could scarcely be inhibitory in the clearer water off the Mull of Galloway where the lower limit was still about five fathoms.

(*b*). The race of *L. cloustoni* in this area is physiologically incapable of growing in depths greater than five fathoms because of its light requirements.

(*c*). There may be a lowering of the salinity from the rivers emptying into the Firth of Clyde. This again, however, would not operate around the Mull of Galloway.

(*d*). Unfavourable substrate. Much of the area is composed of boulders, and the size of these may be such that they cannot maintain larger plants. Off the Mull of Galloway, however, the substrate is solid rock, and there appeared to be very little difference in plant size. For reasons which will be stated later, the present author tends to favour alternative *b*.

South of Ayr Bay (Dunure) the echo-sounder chart indicated small clumps of

weed at four fathoms; the chart was obtained at high water when there were five fathoms over the weed. Between Girvan and Brest Rocks dense *L. digitata* and *L. cloustoni* rarely occurred below three fathoms, but there was an outer fringe of thin weed or of *L. saccharina*. Admiralty charts of this area indicate sand at seven fathoms, and the characteristic distribution here (*L. cloustoni* and *L. digitata* with a seaward fringe of *L. saccharina*) is probably correlated with the nature of the bottom, *e.g.*, a transition from boulders large enough to retain the first two species to smaller stones embedded in sand with *L. saccharina*.

FIG. 2. One of many aerial photographs made along the coast of Great Britain to reveal the presence of commercially valuable supplies of brown seaweed. This one reveals the difference between clearly outlined dark areas of seaweed and similar but less distinctly defined shadows cast by clouds.

South of Girvan, at Ardwell, Clacken-

ray, Pinbain Hill and Carleton Port, a number of shoals run off at an angle from the shore. These each bore dense bottomweed, whilst the intervening deeper areas carried only a light cover or *L. saccharina*. Here again the nature of the bottom is probably responsible for the distribution of the weed, the deeper areas being composed either of small boulders or of stones embedded in sand.

East of the Mull of Galloway a considerable area of Luce Bay is sandy or shingly, and the available evidence strongly suggests that much of the bay is covered with *L. saccharina*, whilst on the boulders near the beaches *L. cloustoni* and *L. digitata* descend to two or three fathoms. This is an area that should be particularly suitable for survey by air photography. Luce Bay also provided an illustration of the relation between rockweed cover and exposure. On the west coast, between Sandside and the Mull, the average cover is 165 tons of *Ascophyllum* per mile of coast; on the east shore, between Glenluce and Port Castle Bay, although there is a wide beach, the average cover is 43 tons per mile. The east shore, however, is fully exposed to the dominant southwesterly gales, and a heavy development of *Ascophyllum* is not possible. The total amount of bottomweed in this area was estimated as 49,000 tons, but as four districts were not surveyed in detail this figure must be an underestimate. The corresponding figure for rockweed was 9,100 tons.

B. Mull area (Loch Leven, Loch Eil, Loch Linnhe, Loch Aline, Loch Sunart, and the shores of the Island of Mull). This was surveyed for rockweed only, but a number of interesting features emerged. Generally the tonnage per mile increased from the mouth to the head of a loch. This could be correlated with increase in width of beaches and with quieter waters towards the head of a loch. Loch Leven proved an exception to the above statement, but the decrease at the head of this loch is probably due to effluents from the British Aluminium Company's factory. At the mouths of large rivers or streams flowing into the lochs *Ascophyllum* disappeared and was replaced by *Fucus ceranoides*. Although this transition is primarily associated with salinity changes, there is also the possibility that a purely mechanical effect may be involved. During the winter the amount of water coming down these mountain torrents is so great that the stones are readily moved; any long plants of *Ascophyllum* would offer increased resistance to the water, and hence render it very easy for the stones with their algae to be removed.

At the heads of the lochs, or sometimes in bays along the shore, salt marsh has developed, and there is a strong growth of the salt marsh fucoids. Apart from dwarf embedded forms there may be free living forms derived from *Fucus ceranoides*, whilst the free-living *Ascophyllum Mackaii* was not infrequent.

The total amount of rockweed recorded in this region was 38,400 tons.

C. The Outer Hebrides. The survey in this region was largely confined to the west coast between the Sound of Barra and West Loch Tarbet in Harris, and was further restricted to bottom weed. The weather was very poor, and it was impossible to obtain numerous observations by the boat and grapnel method. Prior to the aerial survey there had been a westerly gale, and the sea was filled with broken weed and presented a 'soupy' appearance, so the beds did not show up well, even when near the shore. Clouds also interfered with the interpretation of the photographs. The general outline of the bottom weed beds is therefore based upon relatively unsatisfactory photographs together with the scanty grapnel observations. Using the grapnel it was possible to

FIG. 3. One of the many coastal charts showing seaweed supplies and prepared from data furnished by aerial photography, echo soundings and seaweed hauls. This one shows the bottomweed beds off the West coast of Benbecula and South Uist.

establish the approximate lower limit to which bottomweed descended. As this appeared to be fairly constant at about eight fathoms the lower limits of the beds were ultimately plotted along the eight-fathom line as given on large scale Admiralty charts. A similar procedure had to be employed around the Farne Islands. So long, however, as the lower limit of the weed is fairly constant, and so long as sufficient indication about the nature of the bottom can be obtained from Admiralty charts, mapping by this method will yield reasonable approximations.

Large plants of *Laminaria cloustoni* could be found down to depths of five to six fathoms, but below that the plants became progressively smaller until the lower limit was reached. Around the Monach Islands *L. cloustoni* was found at 12 to 13 fathoms, and large plants grew down to ten fathoms. The heavy swell around these islands, perhaps combined with the currents, which are not unduly strong, is probably responsible for the greater and deeper extent of the beds. Between the Monach Islands and Greian Head on Barra there is an almost unbroken shelf of weed, though patches of bare sand occur within it. North of Griminish Point on North Uist a smaller bed extends up to the Island of Pabay, whilst dissected beds occur in the Sounds of Harris and Barra.

There are two features associated with this area but also found elsewhere, to which attention may be drawn. It was noted that a dense weed bed has the effect of 'damping' waves, thus exhibiting a phenomenon similar to that of oil on water. Similar phenomena have been recorded for beds of *Macrocystis* in North America and for beds of *Ecklonia* in South Africa.

In view of the great extent of these Hebridean beds very large casts must be produced. The total tonnage of the bed was estimated at 670,900 tons. If

we assume that the average life of a plant of *L. cloustoni* is four years, then one quarter of that tonnage should disappear as winter cast (140,200 tons), whilst about one quarter of the remainder (133,000 tons) may be sloughed off as 'May cast'. The two combined casts should approximate to 273,000 tons, but of this total by no means all will be thrown ashore. Here we may refer to the second feature found in this area. Some of the cast will be swept out to sea, some will remain floating off-shore, whilst some will accumulate in pockets in the quieter and shallower waters. This proved particularly true of the sounds of Harris and Barra.

D. The Orkney Islands. Both bottomweed and rockweed are extremely rich in this area. The development of the former must be correlated with the presence of suitable substrate and with strong currents which provide excellent aeration. Growth of the latter is correlated with the varied indentations of the coast and the existence therefore of numerous protected areas. The Orkneys illustrate extremely well the difference in growth of rockweed as between protected and exposed localities; *e.g.*, Inner Deer Sound on Mainland where there were 343 tons per mile. Table 2 illustrates the variations in density of rockweed with exposure:

This table shows very forcibly the dependence of *Ascophyllum* upon suitable protection. It has been known for a long time that *Ascophyllum* is usually replaced on exposed coasts by other species, but here quantitative evidence is provided to show that the proportions of *Ascophyllum* are related to exposure.

A similar contrast due to the difference between exposure and protection was observed on North Ronaldsay. On the exposed west coast the rockweed is poor, 47.5 tons per mile, and lacks pure *Ascophyllum*. The east coast is protected from the dominant westerly gales, and here the weed cover was estimated at an average of 246.5 tons per mile with very much more *Ascophyllum* present. Both Stronsay and Shapinsay provided further evidence of the effect of exposure upon the amount of rockweed and also upon the amount of *Ascophyllum* in relation to the species of *Fucus*.

On the south and east coasts of North Ronaldsay there are extensive bottom weed beds extending down to nine or ten fathoms. In Rapness Sound a number of grapnel hauls were carried out, and the results from the hauls agreed extremely well with the distribution of weed as plotted from photos. Around the Orkneys the echo-sounder also proved extremely valuable.

Around the Island of Wyre the echo-

TABLE 2

DISTRIBUTION OF ROCKWEED (*Fucus* AND *Ascophyllum*) ON ORKNEY MAINLAND

Area	*Total weed* (tons) (to nearest 10)	*Mileage*	*Tonnage per mile*	*Total pure Ascophyllum* (tons)
Clivie Bay-Pt. of Ayr	270	4	68	40 (exposed)
Pt. of Ayr-Mikardy Pt.	360	6	60	20 (exposed)
Inner Deer Sound	3,600	10	360	3,260 (protected)
Gumpick-Rerwick	140	2	70	0 (exposed)
Rerwick-Weethick	350	3¾	93	100
Weethick westward	500	4¾	106	20 (exposed)
Inganess and Bay of Meil	1,680	5½	300	1,440 (protected)
Kirkwall	340	2½	136	310 (protected)
West of Kirkwall	150	2½	60	80 (poor beach)
Wide Firth and Bay of Isbister	3,000	12¼	245	2,230 (protected)
Broad Taing-Midgarth	930	5¾	162	270 (moderate protection)
Midgarth-Backquoy	1,100	5½	200	550

TABLE 3

Stronsay Area	*Total weed* (tons)	*Mileage*	*Tonnage per mile*	*Total pure Ascophyllum* (tons)
St. Catherine's Bay-Linkness	730	6¼	116	260 (moderate protection)
Linkness-Hunton	2,140	9¼	231	1,390 (protected)
Pt. of Lenay-Burgh Head	415	7	59	180 (exposure)
Burgh Hd.-Houseby	730	3¼	225	730 (protected)
Houseby-Mt. Pleasant	635	4	159	.....
Shapinsay				
Twinness-Hacksness	1,060	5¼	200	480 (protected)
Hacksness-Ness of Ork	90	5¾	15	0 (exposure)
Ness of Ork-Galt Skerry	1,010	6½	155	560 (protected)
Galt Skerry-Twinness	260	4¼	60	50 (poor beach)

sounder chart yielded evidence of another type of brown alga. Grapnel hauls suggested that this record was given by a dense growth of large plants of *Chorda filum*. The difference in the type of record, if the interpretation is correct, between the *Laminaria* and *Chorda* is very striking. Since *Chorda* is an annual, this marked distinction will be evident only in summer when the *Chorda* has reached its maximum growth.

Ripples on the water beyond Papa Westray caused by wind gave a false appearance of bottom weed; such a phenomenon was experienced several times around the Orkneys.

Mention has also been made of the future use of air photography in mapping supplies of rockweed. In one of our aerial photographs, three important types of rockweed stand out clearly at 3,800 feet. At lower altitudes the distinction is even clearer, and when vertical photographs are employed the mapping of the beds can be accurately performed and the percentage cover estimated.

TABLE 4

ORKNEY SEAWEED RESOURCES

Area	*Total bottomweed*	*Total rockweed* (tons)
Mainland and Wide Firth	7,890	12,580
Shapinsay	8,000	2,420
Wyre and Garisay	.....	1,240
Rousay	54,450	650
Egilsay		870
Eday, Sd. of Fara, Sd. of Rapness	90,600	640
Westray and Papa Westray	75,910	6,570
Sanday	245,270	20,240
Stronsay	46,250	4,650
N. Ronaldsay	48,000	1,880
	576,370	51,740

E. Helmsdale Area (Berriedale to Brora). The bed of bottomweed was not so extensive here as we anticipated. Local fishermen stated that big plants grew down to depths of 10 to 12 fathoms, but whilst in one or two places weed could be found at 10 fathoms the plants were small and puny. A suggestion that there was an inner and outer bed separated by a zone of bare sand received no confirmation. It is true that suitable areas of hard ground exist at 10 to 14 fathoms, but any weed growing on it must be small and widely scattered because neither grapnel nor echo-sounder yielded any positive results. There is no major swell in this region, such as is found in the Monach Islands, nor are the currents comparable in strength to those of the Orkneys; there is therefore no *a priori* reason why *Laminaria cloustoni* should descend here below eight fathoms.

One echo-sounder chart obtained in this region illustrated very clearly the effect of heavy rolling due to severe wave action; the regular spikes were caused by the rolling of the launch, and the difference between that section of the chart and the portion immediately preceding where *Laminaria* was dense is very marked.

For the length of coast involved the area was rich, the bottom weed totalling 59,700 tons, though the rockweed was only 2,400 tons.

F. Balintore Area (Tarbat Ness to Sutors of Cromarty). The proportion of *Ascophyllum* in relation to the species of *Fucus* increased very considerably in Moray and Dornoch Firths. Since the presence and growth of *Ascophyllum* is favoured by protection this result was to be expected. Cromarty Firth proved interesting because the total tonnage of weed was small compared with that of the other two Firths, and the amount of *Ascophyllum* on the north shore was very small. Much of this north shore is unsuited to weed growth, and the only satisfactory substrate is a zone of pebbles and boulders near high water mark of neap tides. This zone is usually too high to carry much *Ascophyllum;* hence the small quantity of this alga.

The area was also interesting because it was the only one in which vertical and oblique air photographs were available for simultaneous interpretation and comparison. Under the conditions prevailing when these photographs were obtained, it became clear that the obliques were more satisfactory and enabled the beds to be mapped to a greater depth. Under different conditions it is probable that vertical photographs would be more successful than obliques. The failure of the vertical was largely due to the effect of waves in obscuring the outline of the bottom weed. The same photograph also shows up the different rockweed species quite distinctly, the *Ascophyllum* being lighter in tone than the *Fucus*. The altitude of this photograph, however, is too great for really successful mapping and interpretation of rockweed species.

In this area it was estimated that there were 52,370 tons of bottomweed and 11,700 tons of rockweed.

In general, the bottomweed of the Balintore area did not extend to quite the same depth as at Helmsdale, the Orkneys and the Hebrides. This seems almost part of a broad development which can be traced on both coasts of Scotland from the Orkneys southward, though obviously subject to local variation. The plants descend to a greater depth in the Orkneys and Hebrides than elsewhere, and as one proceeds south the limiting depth gradually decreases. This phenomenon may perhaps be correlated with the existence of different physiological races of *Laminaria cloustoni* and in this connection it would be very desirable to establish whether the limiting depth increases as one proceeds northwards to the Shetland Isles and the Faeroes. One would also need to consider the behaviour of the species around the coast of England and Wales. Alternatively it may be suggested that as one proceeds farther north from the Scottish Border the water becomes increasingly clearer.

G. St. Andrews Area (Arbroath to St. Andrews, Fifeness and Elie). The bottomweed of this region was initially plotted by means of boat and grapnel. Subsequently air photographs became available, and the bottomweed was replotted and re-estimated. In this area, therefore, one can compare the results of boat and grapnel alone with those from boat and grapnel plus air photographs. The essential details are recorded in Table 5.

From this table one may conclude that in many cases grapnel alone may involve an error of at least $\pm$ 60%. The very substantial increase from Anstruther to Crail was due to the fact that the bed is very dissected. Where the cover is more uniform an error of $\pm$ 60% is probably legitimate.

At Kingsbarns the weed bed was extremely patchy and extended out to sea in the form of long tongues. Differences of tone in the photographs sug-

gested that *L. cloustoni* and *L. saccharina* both occurred in this neighbourhood, but unfortunately no direct confirmation proved possible. The most striking feature about this area was, according to the Admiralty Charts, the presence of a vast shelf of rock stretching out into the sea. From our survey it would seem that this rock shelf is not continuous and that in places only the higher portions remain covered with seaweed, the lower parts being covered with sand or mud. In other places there seems little doubt that bare rock does exist, although the conditions are such that *Laminaria* should be able to extend down to a considerable depth. It would appear that some factor must be operating here which inhibits the downward spread of *Laminaria*, because the lower limit of the beds was about four to five fathoms.

On the northern shore of the Tay the boat survey indicated the presence of an extensive bed of *Laminaria* between Carnoustie and Arbroath. The subsequent air photographs showed that this bed was extremely patchy, and that therefore short of an elaborate survey the grapnel method would inevitably lead to a large error. This bed illustrates very clearly the inadequacy of the grapnel technique. The total amount of weed estimated in all this area was 43,220 tons of bottomweed and 3,000 tons of rockweed.

H. Berwick to Newbiggin. Numerous difficulties with the echo-sounder led to an intensive use of the grapnel method in this area. When this was combined with a study of the Admiralty charts (nature of bottom and course of fathom lines) it was possible to achieve an approximation of the weed bed outlines. Intensive use of the grapnel around Holy Island soon indicated the general depth to which bottomweed descended, and the outlines were completed by plotting along the fathom line on a large scale Admiralty chart, but omitting any area with an unsuitable bottom (sand, mud, etc.). Heavy beds occurred only down to three fathoms, and below that depth to five or six fathoms the plants became smaller or more thinly distributed, even though a suitable substrate was present. Such a procedure should obviously be supported by an aerial survey.

TABLE 5

BOTTOM WEED ESTIMATES, ELIE TO ARBROATH

Area	*Grapnel alone*	*+Photographs*	*% increase*
Elie-Anstruther	9,400	9,360	0
Anstruther-Crail	4,400	12,200	+178
Crail-Kingsbanks	7,040	13,530	+ 92
Kingsbanks-St. Andrews	3,400	5,240	+ 54
Carnoustie-East Haven	8,610	5,209	− 40
Arbroath	9,200	3,201	− 65
		Average	± 71

At Scremerston (south of Berwick) only a fringe of *Laminaria* was reported, yet the Admiralty charts indicated a rock shelf extending down to five fathoms and more. The absence of *Laminaria* here may be due to the deposition of mud and silt brought down by the River Tweed.

In spite of the restricted depth of the bottomweed the total estimated tonnage was 117,770 tons, whilst the available rockweed was calculated as 11,050 tons.

Whilst on this coast the echo-sounder was employed on one or two occasions. A portion of one chart provides an excellent example of how a launch with an echo-sounder can cross and recross the

edge of a bed and so enable a reasonably accurate outline of the lower limit to be obtained.

Cast Weed and Its Sources

It has been assumed that the strong winds which bring the cast ashore are the same winds that break up the beds. In the majority of cases this assumption is probably correct, but in a few cases the destructive gale may keep the cast off-shore until a change of wind causes it to be thrown up. In some areas, *e.g.*, Worbarrow, Lyme Regis, Bridlington, the destructive wind blows across the weed bed and the cast is thrown up either to east or west or to north or south of the bed. In other areas winds from more than one quarter will bring in cast, *e.g.*, Penzance, Girvan, North and South Uist, Helmsdale. In yet other places the bulk of the cast may come from adjacent beds, whilst additional material may be added from more distant beds. This is probably what occurs at Looe and Fowey where there is reason to believe that some of the cast is brought by the long-shore currents (1½ kn. at neaps to 2½ kn. at springs) from the *Laminaria* beds at Start Point. Hence, therefore, a gale occurring at a spring tide period should throw ashore more cast than one occurring with a neap tide.

In certain areas the wind responsible for bringing cast ashore may not be the dominant one, the dominant winds tending to carry the cast out to sea; this is especially true at Worbarrow. Where the cast is thrown up directly by the dominant gale (*e.g.*, Lyme Regis, Exmouth, Newlyn) it should represent a high proportion of the total possible. In some places (Padstow, Bridlington, Thurso) complex causes are in operation and it would seem that cast is ultimately brought ashore by an undertow set up by an off-shore wind.

At Rhosneigr, where there is an extensive weed bed, cast comes ashore only with westerly gales. Gales from the northwest and southwest, which are frequent, would normally bring cast ashore, but powerful currents (2 kn. at neap, 5 kn. at springs) running in these directions would be augmented by the winds and either carry the cast out to sea or else deposit it along the north coast of Cardiganshire. As gale frequency from northwest, west and southwest is about equal, it may be suggested that here only about 30% of the available cast will come ashore annually. A similar phenomenon is to be seen at Gills Bay in Caithness where the bulk of the cast weed will be carried out to sea by currents reinforced by the dominant gales.

On the east coast of Scotland much of the cast weed probably remains in the sea because the dominant gales all blow from off the shore. Farther south, around the Farne Islands, much the same considerations hold, but in addition there may be fairly strong currents in this area which could carry cast considerable distances north or south.

In the following table the amount of cast weed thrown up annually (based on our enquiries) is compared with the amount of bottomweed estimated to exist in the adjacent beds. Estimates with an asterisk are based on figures obtained during the preliminary survey, and they do not have the accuracy of figures obtained during the detailed surveys.

In some of these areas it is probable that the estimates of cast err on the low side, *e.g.*, Helmsdale, Balintore. From Table 6 it appears that 50% is about the maximum percentage of a living bed that may be thrown ashore annually. From the theoretical point of view also the total amount of cast expected would appear to be not more than approximately 50%. If it is assumed that the bulk of the bottomweed beds is composed of *Laminaria cloustoni*, and that the average life of a plant is about four

TABLE 6

Area	*Cast (tons)*	*Bottomweed* (tons)	*Apparent percentage*	*Expectations of percentage*
* Worbarrow	425	860	50	Low
* Lyme Regis area	1,550	12,000	13	High
Girvan area	8,000	17,800	49	High
* Lub Score	300	1,400	21	.....
* Port Erradale	600	6,200	9.5	.....
* Clashnessie	540	4,400	12	.....
* Scourie	200	700	28.5	High
* Clasheddy	700	1,200	58.3	Probably High
Dunnet	1,000	7,260	14	Low
* Gills Bay	2,300	20,000	11	Low
Sinclairs Bay	1,000	6,540	16	About 50% ?
Helmsdale area	900	59,740	1.5	.....
Balintore area	800	46,720	1.7	Low
* Fraserburgh	1,200	10,000	12	Low
Carnoustie	1,200	8,410	12	Low
Elie-St. Andrews	4,500	40,330	11	Low
Scremerstone	2,200	13,100	17	High ?
Seahouse-Cresswell	5,800	54,870	10.5	High ?

years*, then about one quarter of the total tonnage will be removed each winter (winter cast). Of the remaining 75% about $\frac{1}{4}$–$\frac{1}{3}$ in weight will be removed during the spring (May cast). The total loss should therefore be between 44% and 50%. *L. digitata* probably does not have such a long average life as *L. cloustoni* so that the proportion of weed removed would not exceed about 45%. In any area the total amount of weed removed would depend upon the relative proportions of the two species present. It is clear that 50% must be in the region of a maximum yield, whilst a cast of 30% to 40% would indicate that a very high proportion of the available material had been washed ashore.

The area most conducive to growth of rockweed is the Orkneys, but if figures were available it is believed that certain portions of the east coast of the Outer Hebrides would be similar. Protection is an important feature because lochs on either the east or west coasts of Scotland carry a higher tonnage of weed than exposed areas. The greater dissection of the west coast naturally results in a greater number of heavy weed bearing areas than on the east coast.

* Four rings in the stipe are common and there is reason to believe that these are annual rings. Some plants live longer than four years, and Sauvageau (1910) has mentioned ten years for the life of a plant.

Factors Determining the Spread and Depth of Laminaria cloustoni

A study of the geographical distribution of the principal rock and bottomweed species involved in this survey shows that the British Isles are approximately near the centre of the areas. The general environmental factors are therefore unlikely to exert a profound effect upon local distribution because species are most sensitive to such changes at the periphery of their areas rather than at the centre.

If the lower limits of *Laminaria cloustoni* around the shores of Scotland are plotted from west to north and thence to east and southwards, the resulting curve is very instructive and there would appear to be two possible explanations:

(*a*). Conditions in the north are most suited to the growth of bottomweed, a major feature perhaps being a greater clarity of the water, and that as one goes south the conditions become less favourable and the weed cannot descend so far.

(*b*). That there are different physiological races of *L. cloustoni*, and these, by virtue of their biological 'make-up',

descend to different depths. Thus one might postulate a deep-water race in the north and a shallow-water race in the south. Both of these theories required to be examined.

It might be considered that around Scotland there is a general lower limit for *L. cloustoni* at eight fathoms. Extension of the weed below that depth is associated with strong currents (Orkneys) or with swell (Monarch Islands). In the absence of any extensive water movement to encourage growth by additional aeration and supply of nutrients, it could be postulated that light suppy is the normal factor limiting the depth to eight fathoms. In certain places, *e.g.*, Firth of Clyde, the Tay, the light supply may be further reduced by the amount of silt in the water, and hence the lower limit of the weed is reduced to less than eight fathoms. Light supply may act directly through photosynthesis, or it may act in reducing the rate of photosynthesis in relation to rate of respiration. In the latter event it would be the compensation point (*i e.*, the depth at which assimilation = respiration) that is important. Very little work has been carried out on this aspect of algal physiology, though Gessner (6) has shown that turbulence has a profound effect on the respiration and assimilation of brown fucoids.

The second of the two hypotheses put forward above rests upon the discovery by Montfort (7) that there are physiological races or habitat forms of *Laminaria cloustoni*. According to their assimilatory efficiency these three forms were classed as "sun" form, "shade" form and "deep water" form. The third differed from the second in that its assimilatory efficiency was much greater at 10 to 20 m. Three such different races would have different lower limits: it might be postulated that the 'deep water' form is largely restricted to northern waters and the 'shade' form to southern waters, with the 'sun' form or mixtures intermediate. These beds should now be studied and analysed to determine whether such physiologic races exist and are distributed as suggested.

Summary

Details are given of extensive surveys of certain rockweed and bottomweed species around the coast of Scotland. The use of an echo-sounder and air photography improved the accuracy of the survey, but further accuracy could be achieved with the aid of a diver. The weights of the weeds varied considerably from place to place, depending on protection and season of the year. The bottomweed totals in tons were as follows: Girvan (491,000), Hebrides (670,900), Orkneys (576,400), Helmsdale (59,700), Balintore (52,370), St. Andrews (43,-200), Berwick (117,700). The corresponding rockweed totals were: Girvan (9,100), Mull and Lochs (38,400), Orkneys (51,700), Helmsdale (2,400), Balintore (11,700), St. Andrews (3,000), Berwick (11,000).

The quantitative data obtained illustrated on numerous occasions the relative effects of exposure and protection upon *Ascophyllum nodosum*. *Laminaria cloustoni* reached its lower limits at different depths, with a pronounced tendency to descend deeper the farther north one goes. The lower limits of this species may be determined by the percentage of incident light penetrating the water at different latitudes, or it may be associated with the existence of two or three physiological races. It is considered that further work on this second alternative is very desirable.

The work described in this paper was carried out whilst the author was attached to the staff of the Marine Biological Laboratory at Plymouth. The investigation was initiated by the Ministry of Supply, and the author is indebted to that Ministry for their co-oper-

ation during the investigation and for their permission to publish the results. The author also wishes to express his thanks to the late Director of the Laboratory, Dr. S. Kemp, to the Service Ministries, Messrs. Cefoil, and at a later stage to the Scottish Seaweed Research Association for the help they provided. During the course of the survey the author was assisted by Messrs. R. Richens, G. Fogg and R. Lewin.

Since the work was carried out, further investigations have been made by the Scottish Seaweed Research Association (Ann. Rep. 1946). They have published a number of reports with detailed surveys of the rockweeds of certain parts of Scotland. With the aid of a new technique (view finder plus calibrated grab and modified range finder) they have confirmed that bottom weed around Scotland does not grow in measurable quantity below nine fathoms and that it would not be economic to harvest below six fathoms. Using this new technique they have calculated that in the Bay of Firth (Orkneys) there are 45,000 tons, and in Carness and W. Shapinsay (Orkneys) 13,000 tons. They believe that around the whole of the Orkneys alone there may be 1,000,000 tons of bottom weed.

It has also been found that there is a variable relationship between depth in fathoms and density, the variability probably being dependent upon the type of bottom. Thus in Argyllshire:

$$d \text{ (lb/sq. yd)} = 10.2 - 1.15 \text{ f (L.W.M.O.S.T.)};$$

in Scapa Flow:

$$d = 12.9 - 1.4 \text{ f (L.W.M.O.S.T.)}$$

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The Origin of the Cultivated Tomato

The ancestral form of the cultivated tomato was originally confined to the Peru-Ecuador area. After spreading north possibly as a weed in pre-Columbian times it was not extensively domesticated until it reached Mexico, and from there the cultivated forms were disseminated.

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Introduction

THE first references to the tomato appear in the writings of the sixteenth-century herbalists, but they are brief and only identify it as newly introduced into Europe. Although it was soon recognized as a native of America, the precise locality from which it came, who took it to Europe and when it first arrived are still matters of speculation. Two hypotheses have been advanced with regard to its place of origin. Most authorities, notably Sabine (1819), de Candolle (1884), Muller (1940*a*, 1940*b*) and Luckwill (1943*a*, 1943*b*), have agreed that the tomato was transported to Europe from Peru some time shortly after the conquest in 1535. The critical evidence cited is that the early names, "Mala peruviana" and "Pomi del Peru", indicate a Peruvian origin, a supposition which they believed is amply substantiated by the fact that the wild relatives are confined to a narrow coastal area extending from Ecuador to northern Chile. On the other hand, some writers have mentioned the possibility of a Mexican origin, although the actual evidence cited in favor of this view is very meager. Phillips (1821, p. 236) merely suggested Mexico along with South America as a probable center of pre-Columbian cultivation. Later von Humboldt (1811, vol. III p. 133) mentioned the tomato among a list of plants that may properly be considered as Mexican. Both hypotheses have been frequently quoted, but that of the Peruvian origin in particular has been repeated so often, sometimes with the addition of dubious or even fanciful supporting evidence, that it has now become a dogma.

In his "Origin of Cultivated Plants", which was the first systematic study of the origin of crop plants, de Candolle (1884) first applied the method of evaluating all available evidence bearing on each crop. He classified his evidence under the following headings: botany (geographic distribution of species within the genus), archeology, paleontology, history and philology. Whenever it was available, de Candolle placed greater emphasis on the evidence from botany, archeology and paleontology, since he considered it more reliable than that from history and philology. In his discussion of the tomato (p. 290) no archeological or paleontological evidence is cited, nor has any been discovered since. In the first section of the present paper the historical and philological evidence will be reviewed together, where it will be pointed out that de Candolle and others have not considered all of the evidence critically. The second section will deal with the geographic distribution of the various species of the genus *Lycopersicon* in so far as it has a bearing on the origin of the cultivated tomato.

Finally the third section will contain some new observations on the tomatoes of Mexico.

The observations on Mexican tomatoes were made possible by a fellowship from the Guggenheim Foundation. The author is also greatly indebted to the staff of the Rockefeller Foundation in Mexico City; to Dr. J. G. Harrar, the Director of Agriculture; and Sr. Efriam Hernandez X. in particular, who helped in the collection of Mexican tomatoes. Special thanks are due to Dr. Isabel Kelly for her collection of tomatoes from the State of Jalisco. Professors Michele De Filippis, Luis Mungio, H. R. W. Smith and Mr. S. Nussenbaum generously translated critical passages from the historical references. Finally it is a pleasure to acknowledge the helpful suggestions and encouragement received from Prof. Carl Sauer of the University of California.

Historical Evidence

Matthiolus, in the first edition of his commentary on Dioscorides (1544), describes both the eggplant and more briefly the tomato (p. 326) as species of the mandrake (Mandragora). The description of the tomato may be translated freely from the Italian as follows: "Another species [of Mandrake] has been brought to Italy in our time, flattened like the melerose [sort of apple] and segmented, green at first and when ripe of a golden color, which is eaten in the same manner [as the eggplant—fried in oil with salt and pepper, like mushrooms]". This description is considerably amplified in the Latin edition of 1554 which is usually cited as the first reference to the tomato. In this latter edition he gives the common name, "Pomi d'oro", with its Latin equivalent, "Mala aurea", for the first time. In the posthumous edition of 1586, which was edited by Camerarius, there is a wood-cut which leaves no doubt that the plant referred to was the tomato. Furthermore the name "Pomi d'oro" has persisted to this day in Italy as the common name of the tomato. It is notable that the 1544 edition mentions only a yellow tomato, which suggests that this color variant was the first tomato known in Italy, hence the name "Pomi d'oro". However, the more common red-fruited form must have been introduced some time before 1554, since it was mentioned in the edition of that year.

Dodonaeus published the Flemish edition of his herbal in 1554, the same year as Matthiolus' second edition. He describes the tomato in a separate chapter entitled "of Amorous apples or Golden apples". The description together with the wood-cut that appeared in later editions clearly identify the plant as our tomato. He also includes the following list of synonyms: in Latin, "Pomum Amoris", "Poma Amoris", "Pomum aureum"; in French, "Pommes dorées", "Pommes d'amours"; in high German, "Galt offel"; in low German, "Gulden Appelen"; in English, "Apples of love", "Golden Apples". With the exception of the French "Pommes d'amours" and its English variant, "Apples of love", these names are clearly derived from the Italian "Pomi d'oro." It is quite possible that from a single source the tomato spread to both France and Italy where it was named independently. A rapid migration to additional countries is quite understandable, since the internationally-minded herbalists were constantly on the look-out for new and exotic medicinal plants.

Neither Matthiolus nor Dodonaeus speculated on the origin of the plant, though both definitely stated that it had been introduced recently and was grown only in the gardens of the herbalists. The impression is given that the tomato was not considered as a food plant, but rather as a curiosity with probable

medicinal properties. Both noted its resemblance to the mandrake, and Dodonaeus in particular considered its use dangerous.

In Anguillara's Semplici (1561) there is a short note on page 217 entitled "Licopersico di Galeno"; "Quelle poche note, che gli sono assegnate, ponno molto bene quadrare à quella pianta, che al presente si chiama da alcuni Pomi d 'oro, e da altri Pomi del Perù. altri dicono essere sorte di Melenzane". This may be freely translated as follows: Those few notes that are assigned to it could very well fit that plant which at present is called by some "Pomi d'oro" and by others "Pomi del Peru", while others say it is a sort of Melanzane [egg plant, *Solanum melongena*]. This equivocal passage has been interpreted to mean that "Pomi d'oro" and "Pomi del Peru" were two common names applied to a single plant, the tomato, which could very well have been Galen's *Lycopersicon*. Thus on Anguillara's authority two new names, "Pomi del Peru" and "Lycopersicon", were introduced into the synonomy and became firmly established through repetition in subsequent works. In fact the latter has persisted as the scientific name of the genus.

Many authorities, including de Candolle, have assumed that the name "Pomi del Peru" was commonly used during the sixteenth century to designate the tomato and, furthermore, that the fruit was given this name because it came from Peru. However, a critical examination of the evidence shows that these assumptions are based on error. In the first place such authorities have overlooked the fact that this same name, "Pomme de Perou", was earlier applied to *Datura Stramonium* in France (Dodonaeus, 1563, p. 376). Secondly the few sixteenth century references to the tomato by the name "Pomi del Peru" or its variants are clearly based on one interpretation of the passage from Anguillara quoted above. Curiously enough "Pomi del Peru" is given as a synonym for both datura (p. 175) and the tomato (p. 821) in the Camerarius edition of Matthiolus (1586). Finally it is not clear that Anguillara himself considered "Pomi del Peru" as an alternate name for the tomato. In view of Guilindini's speculations on Galen's *Lycopersicon*, which are discussed below, it seems more reasonable to interpret Anguillara's statement to mean that he thought Galen's *Lycopersicon* could be any one of three plants—tomato, datura or eggplant.

Guilandini of Padua (1572, p. 90) also speculated on the identity of Galen's *Lycopersicon*, and his account is much more illuminating. He points out that Galen never actually saw the plant itself, but only the juice that a certain centurion claimed came from a north African plant of that name. The extract had an unpleasant odor, was thought to be poisonous and at the same time to have powerful medicinal properties. On the basis of these characteristics—an exotic poisonous plant with an unpleasant odor—Guilandini suggested that it might be any one of three plants: the "Tatula" of the Turks, the "Pedua" of the Carthaginians or the "Tumatle" of the Americans. His lists of names for those three plants that had already been published by other authorities are extremely revealing:

Tatula: *hyostamus Perunianum, Soanum somniferum, Stramoniam, melospinum, malum Perunianus, solanum Romanum, coronam regiam, pomum spinosum*, etc. [= *Datura stramonium*].

Pedua: *caryophyllus Indicus, tanacetum Perunianum*, etc.

Tumatle: *tumatle ex Themistitan, pomum aureum, pomum amoris* [= *Lycopersicon esculentum*].

It is strange that Guilandini should have thought that either the tomato or the datura could have been Galen's *Ly-*

copersicon, when by at least one authority each was assigned to the New World. Yet Guilandini, without further discussion, implies that they could have been growing in northern Africa at the time of Galen (131–200? A.D.). In general the sixteenth century herbalists had very hazy ideas of geography and plant distribution. Apparently to most of them such places as America and Peru meant nothing more than remote regions, almost synonyms for "foreign".

Guilindini's names for the tomato are especially informative. For the first time the tomato is assigned to America; in fact he gives preference to the American name which is derived from the Nahua word "tomatl". Furthermore the dubious name "malum Perunianus" is clearly assigned to datura and not to tomato. Finally and most important, in referring to the "tomato from Themistitan" he gives the most definite clue when it was introduced into Europe and from where it came. "Themistitan" is a variant spelling of "Temixtitan" which in turn is a corruption of "Tenochtitlan", the native name for Mexico City proper. Cortes dated his letters of 1524 and 1526 at Temixtitan, and this form was preserved for some time, even in official records (Bancroft, 1883 2: 10). However, its use was confined to a brief period immediately subsequent to the conquest; it was soon superceded by the name "Mexico". Consequently it seems reasonable to assume that the tomato was taken from Mexico to Europe soon after the conquest.

The first extensive observations on the tomatoes of Mexico were made by Hernandez who began his monumental study of the plants of Mexico in 1570 and worked until his death in 1578. The completed manuscript was burned in the Escorial, but extracts were published in 1615 and 1651. In the chapter on the tomato (1651, p. 295) the Nahua word "tomatl" is applied to a number of plants belonging to several solanaceous genera, including *Physalis*, *Saracha* and *Lycopersicon*. (cf. Martinez, 1937). This broad use of the word will be discussed below. It was Acosta (1590), however, who first reported seeing the tomato in the New World. Since he describes it as full of juice, it definitely refers to *Lycopersicon esculentum* and not to one of the other Mexican tomatoes. Unfortunately it is not clear from his account whether he observed the plant growing in Mexico or in Peru, but he did refer to it by the modern Spanish name "tomate".

During the seventeenth century some variant of the Nahua name "tomatl" rapidly replaced other names throughout the whole world, though the two original European names have persisted to a limited extent: "Pomi d'oro" in Italy and some variant of "Love apple" in England, northern Europe and the United States. In the spread of the tomato to the orient, which was undoubtedly due to the activities of the Spanish in the Pacific, some form of the Spanish "tomate" went along with the plant. Even throughout South America the plant is known by this same Spanish form of the Mexican word. Up to the present no one has reported any name for the tomato derived from a South American Indian language. This lack of an indigenous South American name is certainly indicative of an origin in North America.

During the latter part of the sixteenth century the herbalists were beginning to consider the relationships of plants and attempted to arrange them in natural groups rather than merely listing them with a diagnostic description and their medicinal properties. As a result they made many combinations of existing names or coined new ones in order to express their concepts of classification. Thus in addition to the names already discussed—"Pomi d'oro," "Pomme d'

amour", "Pomi del Peru", "*Lycopersicon*", "Tomatl" and their derivatives —there appeared a whole series of new names that have no bearing on its origin. For example Camerarius (1588, p. 130) gives the names: "Pomum amoris", "Pomum de oro", "Pomum Indum", "Tumatle ex Peruuiana", "Lycopersico", "Solanum pomiferum". Casper Bauhin (1623, p. 167) lists an even greater number of names that had been applied to the tomato by various authors. This multitude of scientific names is a record of ideas on the taxonomy of tomatoes, but is of no significance in tracing their origin.

Apart from the dubious name "Pomi del Peru", there is nothing in the historical record that even suggests a Peruvian origin of the tomato. On the contrary, all of the evidence, the name "tomatl" and Guilindini's observations in particular strongly point to a Mexican origin. Moreover, the time of introduction favors Mexico. The tomato must have been brought to Europe some time before 1544, which was only nine years after the conquest of Peru but more than twenty years after the conquest of Mexico. This period in Peruvian history was one of strife; the conquerors were dividing their loot and had no interest in agricultural plants. On the other hand, the Mexican conquest was complete by 1523, the country was soon pacified and a systematic exploitation of all colonial wealth was well established before 1544. There was a regular arrival and departure of ships from the port of Veracruz.

The only puzzling fact is the lack of early records of the tomato in Spain; yet it must have passed through Spain, or at least been transported in Spanish ships. Clusius, who was closely associated with Dodonaeus, went to Spain in 1564 for the express purpose of describing the rare plants of that country; nevertheless he makes no reference to the tomato (1576). Although Gerard (1597) reported that he received seeds of the tomato from Spain, Italy and other hot countries, there is some possibility that tomato seeds were sent directly to the Austrian court where the Emperor spent much of his time. The fact that Cortes' fifth letter, dated at Temixtitan, September 3, 1526, was found in the Vienna Imperial Library points in this direction.

Geographic Distribution

Although de Candolle (1884) placed special emphasis on botanical evidence, that is, on the natural geographic distribution of cultivated species and their relatives, the data available to him were so incomplete that he could make only limited use of the method. His argument may be summarized briefly as follows: each crop plant was derived from some wild ancestral species or progenitor; the cultivated form must have originated within the area occupied by the progenitor prior to its domestication; the geographical distribution of related wild species within the genus is often helpful in delimiting the natural or original area of the progenitor. In the light of more recent studies, particularly those of Vavilov and his collaborators, the "botanical method" as applied by de Candolle is open to serious objections.

Vavilov (1926, 1931, 1940) has pointed out that with the knowledge of systematics and distribution of crop plants available to him, de Candolle could determine the region of origin only within rather wide limits. He was able to establish whether a crop was indigenous to the New or Old World, but in most cases his data were insufficient for more precise location. The latter, as Vavilov emphasized, require a detailed knowledge of the systematic units within a crop together with the geographic distribution of these components. Not only must the species within a crop be clearly

delimited, but, more important, the geographic distribution of the subspecific units must be thoroughly studied. Since botanists do not ordinarily recognize ecological and physiological races and varieties, even in wild plants, and usually avoid cultivated plants entirely, surprisingly little suitable data for the study of origins is to be found in botanical literature.

Through extensive study of mass collections, both in the field and in experimental plots, Vavilov discovered several distinct patterns of geographic distribution. For purposes of the present discussion these may be classified in three main types. First, most of the varieties within a crop, together with their related wild species, are concentrated in a relatively small area, usually in mountainous regions. Vavilov called these areas "centers of varietal diversity". Regions adjacent to the centers contain fewer varieties, and still fewer are to be found in areas more remote from the center. Together with the decrease in number of varieties toward peripheral areas there is a corresponding increase in the uniformity of the individual varieties. As compared with the peripheral regions the centers themselves are characterized by many transitional types between the wild and the cultivated forms as well as by a preponderance of dominant genes. It appears that successively smaller and smaller samples of the total variability succeed in migrating to the periphery. A second and more common pattern is characteristic of the older staple crops. Here there is more than one center of varietal diversity. The different centers may represent independent domestication of different species within a single crop, or they may represent secondary centers of variability formed by the hybridization of varieties that migrated from the primary centers by different routes.

Vavilov believed that the first steps in domestication took place within the primary centers and that transportation away from these centers occurred largely through the agency of man. However, he does recognize a third pattern in which domestication may take place far from the original center of variability. In this last pattern, which is characteristic of crops domesticated relatively late, there is a gradual spread of a wild species that flourishes in disturbed ground and in habitats where there is an abundance of nitrogen. Man's participation in the spread during this weedy stage is passive; he supplies the habitat or inadvertently transports the seeds as weeds from one field to another. Through unconscious selection the seeds of the weeds come to resemble the seeds of the crop, and finally in peripheral areas the weeds, if more hardy, may displace the original crop. Vavilov believes that both oats and rye came into cultivation in this manner. On the other hand, the wild species may spread by natural means but can maintain itself outside its original range only in disturbed ground on the borders of fields or on refuse heaps. In both cases domestication of the crop may take place far from its original area of distribution and may occur independently in more than one peripheral area.

Published data on the geographic distribution of species and varieties of *Lycopersicon* are meager. By far the best account is given in Muller's (1940*a*) monograph, in which Muller lists the localities from which herbarium specimens of the various species and varieties have been collected. Since the assembling of these lists was incidental to a taxonomic study of the genus, they are not very satisfactory from the point of view of the origin of cultivated tomatoes. In the first place they represent a haphazard collection of specimens that have been accumulated over a

period of years in several different herbaria. In other words the collections not only are small but can hardly be considered as representing the total range of variability within any taxonomic unit. Secondly there is no consideration of the smaller taxonomic units. Nevertheless these lists do provide some information pertinent to a study of the origin of the cultivated tomato.

Both Muller (1940*a*) and Luckwill (1943*b*) have divided the genus *Lycopersicon* into two subgenera: first, *Eulycopersicon* including the red-fruited species, *L. esculentum* and *L. pimpinellifolium;* secondly, *Eriopersicon,* the green-fruited species, which, according to Muller (1940*a*), consists of the species: *L. cheesmanii, L. peruvianum, L. hirsutum* and *L. glandulosum.* The red-fruited group, including as it does all cultivated forms, has a complex geographic distribution pattern that has been greatly influenced by man. Since the green-fruited group contains no species of economic importance, it may be assumed that their geographic distribution is a natural one in that it has not been disturbed by man. With the exception of *L. cheesmanii,* which occurs only on the Galapagos Islands, the remaining species of *Eriopersicon* are confined to a narrow coastal area, less than 100 miles in width, extending from Ecuador to the northern part of Chile, that is, from the equator to about latitude 30° south. *L. pimpinellifolium,* one of the two red-fruited species, has a similarly restricted range of distribution, being confined to Peru, Ecuador and the Galapagos Islands (Muller, 1940*a*). On the other hand, *L. esculentum,* the cultivated species with all its forms, now has a world-wide distribution in tropical and semi-tropical regions.

Thus, with the exception of *L. esculentum,* the natural distribution of tomatoes is confined to a small region. Since the genus is so small and the species are so closely related to each other, it seems reasonable to assume that the distribution of the wild species of *Lycopersicon* was never larger than it is today. If that is so, it is also reasonable to assume that the cultivated species, *L. esculentum,* was at one time restricted to this same small area. No doubt these facts have bulked so large in the minds of de Candolle and others who favor the Peruvian origin, that they have never examined the historical evidence critically. There is no reason to question the conclusion that Peru and Ecuador are the center of origin of the genus. However, it does not necessarily follow that the center of origin of the genus is identical either with the center of diversity of cultivated forms or with the region where the evolution from the wild to the diverse cultivated forms took place.

Before considering the geographic distribution of *L. esculentum* itself, it will be well to mention briefly the classification of this complex of intergrading forms. Muller (1940*a*) has recognized only the variety *cerasiforme* and the form *pyriforme* as distinct entities within the species. As he points out, the latter form properly belongs among the cultivated tomatoes, since it is distinguished from some of them by a single gene difference. Excluding for the moment the variety *cerasiforme,* which will be discussed below, the geographical distribution of *esculentum* varieties is not very well known. Yet detailed information on the geographic distribution of these cultivated forms, particularly in tropical America, is fundamental to a clear understanding of the origin of cultivated tomatoes.

Following de Candolle (1884, p. 290), both Muller (1940*a*, 1940*b*) and Luckwill (1943*a*, 1943*b*) assume that the variety *cerasiforme* is the ancestral form or progenitor of cultivated tomatoes.

This seems a reasonable hypothesis in view of the evidence available. In fact the larger-fruited forms (2.0 to 2.5 cm. in diameter, Fig. 2) that Muller included within the variety *cerasiforme* may be considered as primitive cultivated types or at least transition forms between the wild *cerasiforme* and the truly cultivated types. Unlike the other wild species, which are confined to the Ecuador-Peru area, *cerasiforme* is found scattered throughout the tropical and subtropical regions of the world: South America, Central America, Mexico, West Indies, southern United States, China, Sumatra, Philippines, Hawaii, Europe, Asia, Africa (Muller, 1940*a*, 1940*b*). As in the case of cultivated varieties, the old-world distribution of *cerasiforme* is undoubtedly post-Columbian and therefore has little bearing on the origin of the cultivated types.

Those who have supported the Peruvian origin (de Candolle, 1884, p. 290; Muller, 1940*a*, 1940 *b*; Luckwill, 1943*a*, 1943*b*) have explained the wide distribution of *cerasiforme* throughout tropical and subtropical America by numerous reversions from cultivated varieties. They assume that cultivated tomatoes originated somewhere within the Peru-Ecuador area by long-continued selection of variants of *cerasiforme* having larger fruits. Subsequent to their origin, cultivated tomatoes were transported by man to other parts of South America and ultimately to North America. In numerous places tomatoes escaped from cultivation, and, owing to the release of artificial selection pressure, they again reverted to wild *cerasiforme*. On this hypothesis the process of reversion must have occurred repeatedly as cultivated tomatoes were transported throughout the Old World.

It is true that under favorable climatic conditions cultivated tomatoes do escape and maintain themselves, for a time at least, in the neighborhood of cultivated fields. But it has never been demonstrated that they ever revert to *cerasiforme*. On the contrary, genetic evidence indicates that if reversion occurs it must be a rare phenomenon and certainly not nearly so common as assumed by proponents of this hypothesis. Since tomatoes are largely self-fertilized, evolutionary shifts of the magnitude demanded by the reversion hypothesis are undoubtedly dependent upon the occurrence of new mutations. Hybridization studies between the primitive two-loculed *cerasiforme* and the cultivated types with three or more locules have shown that the two-loculed condition is dominant. Consequently reversion from cultivated types with more than two locules would require frequent reverse mutations from recessive to dominant. In view of the relatively low mutation rate of dominant to recessive in tomatoes (Lindstrom, 1941; Rick, 1945), reverse mutations from recessive to dominant must be exceedingly rare.

Reversion from two-loculed cultivated types to *cerasiforme* may occur considerably more frequently than reversion from the more-than-two-loculed types. However, the studies of Lindstrom (1935), MacArthur and Butler (1938) and Powers (1942) showed that the inheritance of size differences between large and small two-loculed tomatoes is complex. The size differential is due to many gene differences, each with a small effect. Again assuming that major evolutionary changes in the tomato are largely dependent upon the occurrence of new mutations, it is easy to see that, on the average, reversions to *cerasiforme* from the larger two-loculed types will require more mutations and take a correspondingly greater time than reversions from the smaller two-loculed types. Considering the small number of plants involved, the chances of the larger two-loculed types persisting outside cultivation for a sufficient length of time to

revert completely to *cerasiforme* is slight. Thus if reversion is an explanation of the widespread distribution of *cerasiforme*, the types that reverted were two loculed types, probably not much larger than *cerasiforme* itself.

The wide-spread distribution of *cerasiforme* can be explained without resorting to the dubious hypothesis of reversion. As postulated by Vavilov (1926), either by disturbing the soil by cultivation or providing areas around his habitation rich in nitrogen, man could have created a habitat particularly favorable to *cerasiforme*. It could then have been spread over vast areas by birds or other natural agencies, without any active participation by man. The dispersal of *cerasiforme* as a weed would explain why the variety was so frequently associated with man. Furthermore, once this ancestral variety was widely distributed, domestication could have taken place anywhere within the expanded area, even in a region far from the center of the genus in Peru and Ecuador.

The Tomatoes of Mexico

During a visit of several months the author had an opportunity to observe both the wild and cultivated tomatoes of Mexico. Some general impressions gained during that time, having a bearing on the origin of the cultivated tomato, will be reported briefly. As mentioned above, *esculentum*, including the variety *cerasiforme*, is the only species occurring in Mexico. Both wild and cultivated forms of this species are found throughout the country wherever the temperature and water supply are favorable for their growth. However, the region to the north of the Tropic of Cancer is of little importance in a study of the origin of the cultivated tomato. A few collections of *cerasiforme* have been made in this arid region, principally along the streams close to both coasts. In addition there is a large area of commercial tomato growing in the State of Sinaloa on the west coast and a somewhat smaller area in and near the State of Tamaulipas on the east coast. Both of these areas were established within the present century for the purpose of supplying the United States market during the winter season, and in regard to the varieties grown, they may be considered as an extension of the United States tomato area. Consequently, with the exception of the few occurrences of *cerasiforme* mentioned immediately above, the aboriginal tomatoes of Mexico are found south of the Tropic of Cancer, the area of high culture in pre-Columbian Mexico.

The most notable fact about wild tomatoes (*L. esculentum* var. *cerasiforme*) throughout Mexico is their close association with man's activity. The variety is commonly found in disturbed ground on the borders of fields, in road cuts and along stream banks, wherever there is sufficient moisture and yet some protection from grazing animals. It is not an aggressive plant that covers large areas, but is rather inconspicuous, occurring as single individuals or in small isolated groups. In short it does not behave like a well established native plant, but one that has been introduced and has spread in association with man. Standley (1928, p. 330; 1931, p. 354) noted that it behaved as an introduced plant also in Panama and in Honduras. Presumably this behaviour is characteristic of the variety throughout Central America and Mexico, and may even be true in parts of South America. In any case, since even the wild variety behaves as an introduced plant, the tomato is not indigenous to Mexico.

Assuming that the tomato was introduced into Mexico, two important questions immediately arise: When was it introduced? and, in what form was it introduced? That is, was it introduced as the wild *cerasiforme* from which the

cultivated types were derived? Or was it introduced as a cultivated type from which *cerasiforme* arose through reversion? While it is impossible to answer either of these questions with certainty, there is considerable indirect evidence bearing on them.

As mentioned above, the wild variety *cerasiforme* is found in all parts of Mexico south of the Tropic of Cancer and in scattered locations to the north. It is most abundant at the lower elevations, especially in the southern coastal areas where there is a moderately heavy rainfall. It appears on the high central plateau only in favorable locations during the rainy season, and is much rarer in the more arid northern regions. Similarly, cultivated tomatoes are grown in all regions where there is sufficient moisture and favorable temperatures. For the most part they are grown for the local market. However, with improvement in transportation, two areas of commercial plantings have been developed: in northern Veracruz and the neighboring regions of Puebla on the east coast; and in Jalisco in the region of Lake Chapala toward the west coast. In contrast with the northern commercial areas, only Mexican varieties are grown in the Veracruz and Jalisco regions. Furthermore these tomatoes are not shipped out of the country but to the high plateau where the lower temperatures and greater aridity shorten the tomato season. This wide-spread distribution of both wild and cultivated tomatoes in a country of more or less primitive agriculture would certainly argue against recent introduction.

Coupled with the wide-spread distribution of tomatoes in Mexico is an equally wide-spread use of them, even by the Indian population in rural villages. In the poorest markets and in the remotest villages there are usually tomatoes for sale during the season, and nearly every housewife, no matter how poor, buys at least one or two. Not only are the cultivated types sold extensively throughout the whole country, but in those regions where the wild *cerasiforme* is abundant the whole inflorescence with the fruits adhering are offered for sale in quantities of a bushel or more. These small wild fruits are considered more tasty than the large cultivated types. It is highly improbable that a people who have retained their ancient food habits as tenaciously as have the Mexicans, could possibly have incorporated the tomato so extensively into their diet in the comparatively short period since the Spanish conquest. Moreover, the use of tomatoes in hot sauces with the native capsicum is quite distinct from European usage.

Further evidence for the ancient introduction of tomatoes into Mexico is to be found in the great diversity of wild and cultivated forms now growing there. With the exception of the multiloculate beefsteak tomatoes, which were developed in the United States during the last half-century, every type known to cultivation may be found in Mexico. Moreover, there are in Mexico many transitional forms between the wild *cerasiforme* and the cultivated types as well as between cultivated types themselves. Many of these transitional forms have not been reported from any other region. In other words the amount of genetic diversity within Mexico is rivalled only by that of the world collections which have been assembled for the express purpose of studying genetic diversity. In no other region, with the possible exception of Peru and Ecuador, from which there are at present no data, is there such a great range of tomato types as in Mexico.

This wealth of genetic diversity in Mexico extends also to the mutant forms. For example the following single gene mutants were found in the Veracruz area: yellow flesh, tangerine flesh, col-

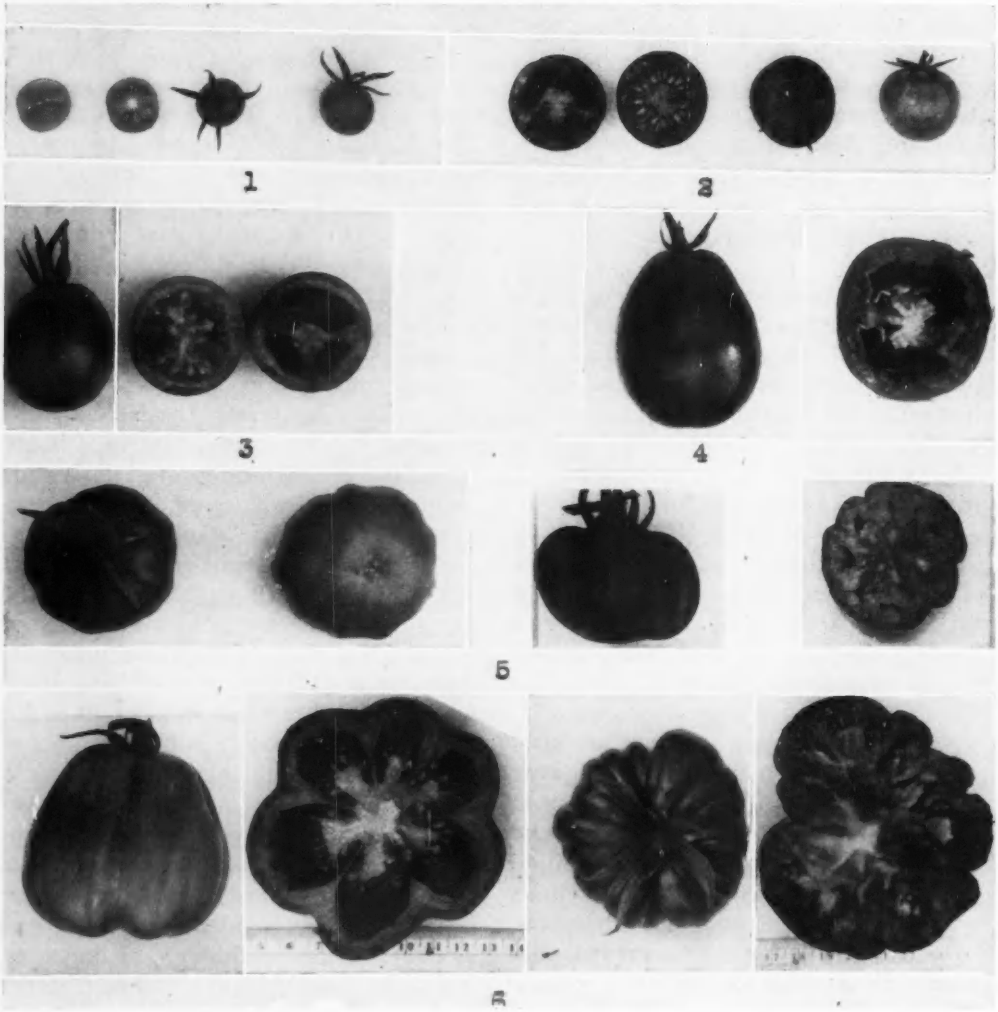
orless skin, pyriform fruit shape, fasciated fruit. The first two are comparatively rare, but the latter three are exceedingly common. In fact fully half of the tomatoes of Mexico have colorless skin which imparts a pinkish cast to the ripe fruits. Thus all the mutant types, with the exception of those that are definitely known to have arisen subsequent to the European introduction, may be found in Mexico today. Furthermore, their widespread occurrence, even *cerasiforme* having white-skinned and yellow-flesh forms, suggests a primary source rather than post-Columbian introduction.

The great profusion of native names applied to both wild and cultivated tomatoes in Mexico gives additional support to the hypothesis of ancient introduction. The following brief account is far from an adequate study of this subject, but it will serve for the present purposes. Considering first the wild variety, *cerasiforme*, the Nahua-speaking peoples and those conquered by them usually refer to this variety by some variant of the word "tomatl", with either a prefix or a descriptive adjective, or sometimes with both. Occasionally the descriptive adjective is used by itself. The following variants are most common: xaltomatl, jaltomatl, jaltomate (sand tomato); "miltomate" (milpa or field tomato); "tomate silvestre" (wild tomato); "cuatomate", " cuatomatillo" (snake tomato?). In the Veracruz area, where this last variety is most abundant, in addition to the above names it is also known as: "tomate chitalino", "chitalillo", "chitalito", "sitalillo" (star tomato); "tomate de venado" (deer tomato); "ojo de venado" (eye of a deer); "chiltomate" (red tomato); "tomatillo" (little tomato). In Oaxaca, the region occupied by the Mixtecs and the Zapotecs, who were ultimately subjugated by the Aztecs, such names as "chinana" and the variants "pethoxi", "bethoxi," "bituixe" probably represent the survival of an independent set of names. The Mayan peoples, still farther to the south, though conquered by the Aztecs, apparently never took up the Nahua names at all, but retained their own distinctive terminology: "mehen p'ak (small tomato); "k'ashil p'ak" (wild tomato); "pac", "paak", "ppac", etc. in Yucatan, and "tsajal chichol" (red tomato) in neighboring Chiapas. The Tarascans of Michoacan, who were never conquered by the Aztecs, uniformly refer to *cerasiforme* as "tinguaraque." The fact that entirely different names were used in different ethnic regions certainly argues for an ancient introduction.

Before dealing with the names of cultivated tomatoes in Mexico, it will be well to consider briefly the Nahua word "tomatl". Throughout Mexico it is applied to several different solanaceous plants, including species of the genera *Lycopersicon*, *Saracha* and *Physalis*, especially to the latter genus (Martinez, 1937). In the Valley of Mexico and the territory to the north and to the west, which is the center of Aztec culture, the word "tomatl", or "tomate", by itself usually refers to some form of *Physalis*. In this area the latter is far more abundant both as a wild plant and as a field weed than is *L. esculentum*. Moreover there is a multitude of forms: most of the wild species have berries about a centimeter in diameter or even smaller, but the large cultivated forms range up to five or more centimeters in diameter. Because of its great abundance together with its long season of bearing in this central plateau region, it is more commonly used as an ingredient of sauce than is *L. esculentum*. The great improvement in size that has occurred during its domestication certainly suggests a long history of cultivation. It is undoubtedly the original tomato of the Aztecs and related peoples. On the other

hand, in the more southern parts of Mexico and among the Mayan peoples of Yucatan in particular, *Physalis* is rarely used for food. In recent years, however, its use has been learned from Mexican garrisons stationed there.

Throughout most of Mexico the cultivated tomato is known as "xitomatl", "gitomate" or "jitomate" (bush? tomato). The different types are distinguished by additional modifiers, for example, "jitomate de bule" (gourd



Types of Tomatoes from Mexico

1. *Lycopersicon esculentum* var. *cerasiforme*, La Ceiba, Veracruz.
2. *L. esculentum*. Transitional type between var. *cerasiforme* and the commonly cultivated types. Tolome, Veracruz.
3. *L. esculentum*. Plum-shaped, two- to three-loculed type. Tenamaxtlan, Jalisco.
4. *L. esculentum*. Pear-shaped, two- or three-loculed type. Tehuacan, Puebla.
5. *L. esculentum*. Small spherical multi-loculed types. Tehuacan, Puebla.
6. *L. esculentum*. Large irregular multiloculed types, from left to right, Tehuacan, Puebla; Puebla, Puebla; Tehuacan, Puebla; cross section of another fruit from the same plant immediately preceding. Magnification × ½.

tomato); sometimes the noun "jitomate" is omitted entirely. The types with their common descriptive names are:

Oval two-loculed types
- plum: "peron" (plum)—Fig. 3.
- pear: "bule", "calabacito", "guajito" (gourd), "guajillo" (little gourd)—Fig. 4.

Multiloculed types
- small spherical: "redondo" (round), duranzo (peach)—Fig. 5.
- large irregular: "costillon" (ribbed), "gajo" (segmented) "riñon" (kidney)—Fig. 6.

The most notable thing about this set of names is the constancy of the word "jitomate" and the fact that most modifiers are Spanish in origin. In Yucatán, on the other hand, even cultivated tomatoes are known by some variant of the word "p'ak", oval tomatoes: "kolil p'ak" (milpa tomato), "chu p'ak" (gourd tomato); small spherical multiloculed tomatoes: "pa'k"; large irregular multiloculed tomatoes: "nohoch p'ak" (great tomato). Thus there are two distinct sets of names for the cultivated tomato in Mexico, "jitomate" and "p'ak". This is a remarkable contrast in view of the great abundance of local names for the wild *cerasiforme*.

The widespread distribution, its importance in the diet, the great diversity of types and finally the profusion of names, especially of the wild *cerasiforme*, certainly indicate that the tomato is not a recent introduction into the country. Furthermore, the great number of distinct names for *cerasiforme* indicates that its introduction was far back in pre-Columbian times. In fact all of the evidence cited is consistent with this hypothesis that the tomato has been in Mexico for several hundreds of years.

Returning to the more difficult question as to what form or forms of tomatoes were introduced into Mexico, the evidence is not so clear. The variety of distinct names for *cerasiforme* together with the comparative uniformity of names for the cultivated types indicate that the former was much better known over a wider area and of more ancient use than the derived cultivated types. Furthermore, the concentration of varieties in the Veracruz area, which includes some types that do not grow elsewhere, indicates that much if not the bulk of the evolution from the small two-loculed tomato took place in Mexico.

Summary and Conclusions

Two important facts emerge from this discussion of the origin of cultivated tomatoes. First, the center of the genus *Lycopersicon* is in South America in the narrow west-coast area between the Andes and the ocean extending from the equator to about thirty degrees south latitude. Secondly, Mexico, the Veracruz-Puebla area in particular, is a center of varietal diversity of cultivated tomatoes. Up to the present there is no evidence of other centers, but it should be emphasized that very little is known of the cultivated tomatoes of other regions of the New World.

It is reasonably certain that Mexico and not Peru was the source of the cultivated tomatoes of the Old World. It is even possible that the cultivated types now found in South America originally came from Mexico.

Since there is as yet no evidence for pre-Columbian cultivation in South America, Mexico is very probably the only center of domestication of the tomato. It should be emphasized, however, since we know practically nothing of the distribution of cultivated varieties in South America, that this conclusion is subject to modification.

With the evidence at hand it seems reasonable to set up the following working hypothesis: *Lycopersicon esculentum* var. *cerasiforme*, the putative an-

cestral form of the cultivated tomato, was originally confined to the Peru-Ecuador area. It spread in pre-Columbian times as a weed of fields and door yards throughout much of tropical America, either with or without man's active cooperation. In Mexico, due to its general similarity to the older food plant *Physalis*, it was domesticated, and from Mexico the cultivated forms were taken to Europe and other parts of the Old World.

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Cork and Cork Products

At least $20,000,000 worth of cork products are annually manufactured in the United States, and efforts are being made by annual plantings of cork oaks in 25 States eventually to relieve American industry of its present total dependence upon foreign sources to supply the cork for this production.

GILES B. COOKE

Crown Cork and Seal Co., Baltimore, Md.

Previous articles on cork (1, 2) have informed the reader about the culture of this product in Spain and experimental plantings in California. It is of interest to point out that plantings of the cork tree are made annually in 25 States in the warmer parts of the United States. This cork-planting program was initiated by the late Charles E. McManus, former President of the Crown Cork & Seal Company, in California in 1939. The widespread interest and response to his efforts in California led Mr. McManus to extend his program into all States where the cork tree might grow and to establish the McManus Cork Project. The purpose of the Cork Project is to add to the natural resources of our country and to provide in the United States a source for at least a part of the nation's cork requirements. In a comparative study of climatic and soil conditions in the cork-producing areas of Europe and Africa with the United States, Ryan (3) has shown that all or parts of 27 States in this country are suitable for growing cork trees. The McManus Cork Project is a long-range program, and it is gratifying to note that results of initial efforts are encouraging.

Cork has numerous important applications. For more than 2,300 years it has served many useful purposes, and for centuries has been a valuable article of commerce. Cork is a necessary material for our national economy both in war periods and in peacetime. For normal manufacturing requirements in the United States about 160,000 tons of cork are imported annually.

In addition to its valuable cork bark, the cork oak produces each year large acorns in generous quantities. This annual crop is used in Europe as a supplemental stock food, and in Portugal alone 200,000 tons of cork acorns are fed to hogs each year. A bushel of cork acorns (about 70 pounds) will make approximately 6.5 pounds of pork.

The cork oak is an evergreen and makes an attractive ornamental shade tree. The tree grows well under favorable conditions, and in four or five years attains attractive size. Its heavy green foliage during the winter months is a delightful contrast to the bare branches of deciduous trees.

Thus, we see, the cork oak returns to its owner much more than many other trees. In addition to wood and shade we obtain from the cork oak, cork, a material essential to our national economy; an annual acorn crop that is excellent for livestock food; and ornamental beauty throughout the year. For these reasons the cork oak may be grown either as an ornamental shade tree or as a forest tree.

Baled cork is brought to the United

PIER 4

States in large freight boats. The bales vary in weight, ranging from about 150 to 250 pounds. During the transfer from boat to storage shed the bales are classified into groups according to quality.

As with all other materials the characteristics of cork determine its uses. Accordingly, before discussing the uses of cork, a brief summary of the physical and chemical properties is presented.

Structure and Characteristics

Under high magnification the characteristic cellular structure of cork can be seen. The cork cells vary in size but are very small, and they number about two hundred million to the cubic inch. They are filled with air and held together by a natural resinous binding substance.

Professor Lewis (4), of Harvard, has shown that the cork cell possesses fourteen sides, six of them being quadrilaterals and eight of them hexagons. This formation is due to nature's method of giving the cells the greatest possible volume with the least amount of surface while permitting the cells to lie compactly together.

The physical attributes of cork are a direct result of its characteristic air-filled cellular structure. Cork is compressible and resilient, and these properties enable it to give a perfect seal when used as a crown cap liner. Each tiny cork cell functions as an air cushion, permitting the crown cap to be compressed firmly against the mouth of the container and constantly exerting a back pressure, thus making a tight and permanent seal.

When cork is placed under a heavy load the air in the cork cells is compressed and the cork is reduced in thickness. When the load is removed the air in the cells expands to normal volume and the cork returns to its original size. One inch cubes of cork have been subjected to a pressure of 10,000 pounds per square inch without any side spread. After the pressure was released the cork returned to ninety-five per cent of the original height.

Both the natural resinous binder and the air-filled cork cells are impervious to water, giving cork many uses where a water-proof material is required. Cork is also oil-resistant, and on account of its non-capillarity, which results from its unique cellular structure, penetration of cork by liquids in general is extremely difficult. For this reason cork can be used as a bottle closure for innumerable solutions and liquids.

Cork is very light, its specific gravity varying between 0.15 and 0.20. This lightness is due mainly to its air-filled cells. The cork cell walls and the natural cell-binding material are also light weight substances. This property of cork gives it many applications where floats and articles of low density, such as insoles for shoes, are required.

Air in finely divided spaces is the best thermal insulator known, next to a vacuum. The tiny air spaces in cork are responsible for the heat-insulating property of cork. The thermal conductivity of cork is very low, and corkboard is an excellent material for low temperature insulation. This property, coupled with its lightness and its resistance to penetration by water, makes corkboard an ideal insulator for refrigerators and air-conditioned buildings.

Cork with its characteristic air-filled cellular structure makes an efficient machinery isolation material. Vibration and wear are greatly reduced by mounting motors and machines on cork. Sud-

FIG. 1 (*Upper*). Unloading a shipload of cork at an American port.

FIG. 2 (*Lower*). In manufacturing molded inlaid linoleum the pattern is stenciled in the desired colors onto the burlap backing. (*Courtesy Cork Institute of America.*)

den pressures and shocks cause the air-filled cells to quickly compress, and the vibrations are not transmitted through the cork.

When cork is sliced, many of the cells are cut, forming thousands of tiny cups on the surface. In these cups partial vacuums are formed when cork is drawn over or pressed against a smooth surface. This accounts for the high coefficient of friction exhibited, and for the suitability of cork where a material of non-slipping character is essential.

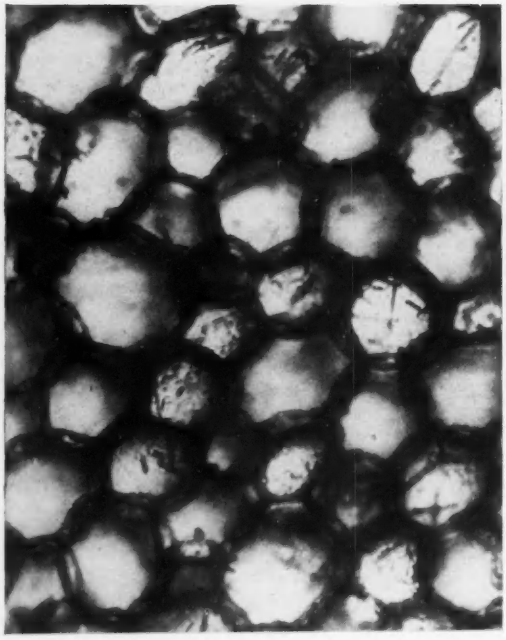

Fig. 3. Photomicrograph of cork showing its characteristic cellular structure. Magnification (500×).

The air-filled cells also give cork an important place in modern building. Corkboard is used to insulate against outside noise and to absorb sound formed within and prevent echoes. Radio studios and motion picture studios have found cork to produce excellent acoustical conditions.

These physical characteristics of cork together with its chemical stability are responsible for its many varied applications. And because no other naturally occurring or synthetic material possesses all of these physical properties, cork is today the basis of a large and flourishing industry.

For centuries the stability of cork has been an outstanding chemical characteristic and has made it suitable for many diversified applications. Clean cork of commerce is not affected or changed in composition by contact with water, vegetable, animal or mineral oils, gasoline, many organic solvents and many gases, such as carbon dioxide, hydrogen, nitrogen and air. Cork is highly resistant to fruit and vegetable acids, concentrated hydrochloric acid, animal acids, soaps, mild alkalis, salts and literally thousands of chemical compounds. Its use as a closure for innumerable articles of commerce attests the chemical resistance and durability of cork. No other untreated naturally occurring plant product can be used in contact with so many different materials.

The constituents of cork are responsible for this remarkable stability over such a wide range of conditions. Over fifty years ago cork was found to contain fatty acids. It is surprising to many users of cork to learn that it may contain as high as thirty-five percent of fatty acids (5). Lignin constitutes from twenty to thirty percent of cork. The cell walls are composed of cellulose and substances that closely resemble cellulose. Other chemical compounds in cork are polyterpenes (6) and tannins.

Natural Cork

Numerous articles are manufactured from natural cork. Among these, cork stoppers are, without doubt, the most familiar. For centuries cork has been used as a stopper for jugs, jars and bottles. We read in Virgil's Ode III, 8: "Corticem adstrictum pice demovit am-

phorae", that is, "remove the cork sealed with pitch from the wine vase". Later on after the invention of the glass bottle in the seventeenth century, the demand for cork stoppers increased rapidly. Such use continued to expand, and in 1892 the now well-known crown cap, a metal closure lined with a cork disc about one-tenth of an inch thick, provided a permanent seal that previously required a two inch cork stopper.

FIG. 4 (*Left*). This large cork oak in Union, South Carolina, is an attractive useful shade tree.

FIG. 5 (*Right*). Hon. Jim McCord, Governor of Tennessee, planting a cork tree on the State Capitol Grounds at Nashville.

Natural cork is used in hundreds of articles more or less familiar to everyone. Hats and helmets for use in hot tropical climates are often lined with cork. It makes a light head covering and gives protection against the heat. Life preservers are made of natural cork. Pieces are trimmed and shaped to fit the pockets of the canvas jackets. Sometimes two or more pieces are skewered together to give the desired size and shape. Cork-tip cigarettes are the favorite of many. Numerous kinds of cork floats are used on seines and nets and on the individual rod and reel. Measuring gauges for liquids of low density, for example, gasoline, are constructed with floats of natural cork. The "bird" used in the game of badminton is made of cork. Natural cork is used for baseball centers to give resiliency and lightness, on penholders for softness and firmness of grip, and as liners for sealing toilet articles in many types of caps.

Natural cork products cost relatively much less today than forty years ago because of modern methods of utilizing the trimmings and other pieces of cork that formerly constituted a huge amount of waste. This portion of corkwood is now ground and purified and used in manufacturing many types of composition cork.

Composition Cork

Composition cork is prepared by coating clean, soft granules of cork with suitable adhesives and curing the adhesive after the coated cork has been placed in molds. The adhesive is applied in such a manner that each cork particle is coated with only a very thin film. Therefore it is apparent that composition cork consists mainly of natural cork. In the photomicrograph of natural cork the cells can be seen held together by a natural resinous adhesive. Composition cork differs from natural cork in that a portion of the binding adhesive is artificial.

The need for composition cork became apparent fifty years ago. The task of making this product was not an easy one, and the early types of composition cork exhibited various imperfections. However, in 1912 Charles E. McManus invented the perfect composition cork for the closure industry. Following this development the use of composition cork rapidly expanded. In addition to extensive use in the beverage fields, composition cork became an important material for manufacturing gaskets of many kinds, shoe innersoles, polishing wheels, friction rolls, cap liners for toilet preparations and numerous other articles.

Composition cork may be prepared in almost any form. It is molded in rods, flat blocks, round blocks and special shapes. The same process is followed in making the rods and blocks, although the size of the cork particles may vary. More adhesive is required to cover a given quantity of finely granulated cork than coarse particle cork, since the surface area to be covered is greater. Among the adhesives generally employed are synthetic resins, animal glues and vegetable glues. The adhesives must be odorless, tasteless and non-toxic when the composition cork is used to seal beverages or food products.

Cork is granulated in special mills which yield pure, clean, resilient granules. The granulated cork is transferred to mixing machines and the proper amount of binder is added. A predetermined quantity of the binder-coated cork is placed in the tube or mold which is then heated. The exact temperature and duration of the heating period depend on the nature of the adhesive binder and the size of the mold.

Composition cork rods are sliced into wafers or discs which form liners for crown caps. For larger caps the liners are stamped or cut from composition cork sheets. The blocks of composition cork are cut into sheets from which hundreds of needed articles are made. Composition cork blocks may be of any practical size, but the weight of the heavy molds and the necessary baking time generally determine the dimensions. Composition cork blocks may be made as large as $5' \times 2\frac{1}{2}' \times 2\frac{1}{2}''$. The sheets are cut into various thicknesses, depending upon the ultimate use. The round blocks are sliced into very long or continuous sheets in a process that revolves the blocks against a sharp knife.

In manufacturing composition cork the unique physical characteristics of natural cork are retained and the chemical properties of the finished product correspond closely to those of the natural material. The artificial adhesives employed are soft, resilient and durable. Each granule of cork which is composed of thousands of tiny air-filled cells held together by the natural cork resin is soft and compressible. Composition cork is manufactured strong and flexible, and it is not attacked by any chemical that does not weaken natural cork.

By varying the density of the blocks composition cork for many purposes can be prepared. Variations in density are effected by altering the type and quantity of adhesive employed, varying the particle size of the granulated cork or

FIG. 6. Bales of cork being inspected in the warehouse.

by employing different amounts of binder coated cork. Through such changes in formulation and manufacture composition cork can be produced to meet a wide range of industrial requirements. Thus composition cork is available in properties and dimensions for many industrial applications that natural cork cannot serve.

Composition cork might well be called

the complement of natural cork. While the manufactured product has in some instances replaced the natural article, at the same time composition cork has supplemented the use of natural cork and greatly broadened the field which cork serves.

Corkboard

The manufacture of corkboard insulation consumes a high percentage of our imports of unmanufactured cork. Natural cork, because of its air-filled cellular structure, is very resistant to the passage of heat. The heating of cork to produce corkboard causes cork to expand and increases this inherent thermal insulating property.

Corkboard insulation was invented in 1892 by John Smith of New York. Some pieces of cork were heated unintentionally in a metallic container and, when cool, were found to be a strong unit mass. Heat had caused some of the resins present in cork to come to the surface of the particles and bond them together. Also, the expansion of the cork under heat forced the particles to spread into the voids and interlock, thereby forming a strongly united mass.

Since the invention of John Smith, many improvements have been made in the manufacture of corkboard insulation. There are several processes employed today, and each is based on the discovery made by Smith over fifty years ago that cork expands when heated and that some of the resins are brought to the surface. Cork is granulated into coarse particles which are transferred to molds and the covers placed on securely. In one process super-heated steam at approximately 600° F is passed through the cork. Another method is by oven baking which is slower and requires from four to six hours at temperatures ranging from 500 to 600 degrees F. Blocks of corkboard vary in thickness up to 15″, and the slabs are cut from one to six inches thick. The usual size is 12″ × 36″, but sometimes corkboard is

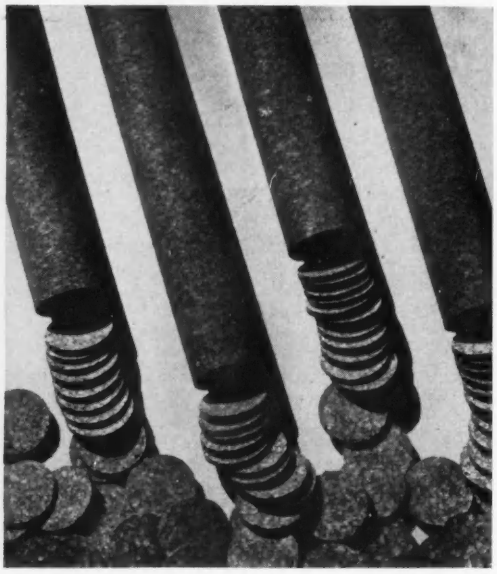

FIG. 7 (*Left*). Cork is an excellent low temperature insulation material.

FIG. 8 (*Right*). Composition cork rods are cut into disks which form the sealing liners of crown caps.

manufactured as large as 36″ × 36″. The baking operation removes from cork some of the more volatile constituents, which removal together with expansion yields a product of low density. Trimmed corkboard insulation weighs from 6.5 to 9 pounds per cubic foot.

The air-filled cellular characteristic of corkboard makes it a valuable material for machinery isolation. The resilient corkboard absorbs shock, reduces vibration and prolongs the life of the mounted machine. Machinery isolation corkboard is heavier than insulation corkboard, the density varying up to 24 pounds per cubic foot. The porous surface characteristic of corkboard is excellent for absorbing sound waves and reducing noise. Corkboard has extensive use as an acoustical material, for which purpose the low density product is used.

Linoleum

Linoleum was developed in 1863 by Frederick Walton of Yorkshire, England. Originally the product consisted of oxidized and polymerized linseed oil, cork and a backing of burlap or canvas. Cork is intimately mixed with the tough, rubber-like oil product and the mixture rolled onto burlap sheets. The burlap backing gives strength to the linoleum, while the oxidized oil and cork provide softness and resiliency.

The manufacture of linoleum was begun in the United States in 1873 and now constitutes a large and very important industry. The attractive patterns available today are the result of many developments and improvements during the past eighty-five years, but the composition of linoleum has remained essentially the same. Pigments and resins are employed now along with cork, linseed oil and burlap.

The cork used is of the best grade and is ground to a fine powder. In this condition the cork can be intimately dispersed throughout the oxidized oil and resins, giving a resilient product that can be calendered to a smooth surface. In some light colored linoleums, wood flour is substituted for the tan colored cork flour. Rosin and kauri gum are the resins generally employed. Pigments are added to give the desired shade. Linoleum is manufactured plain and in a large variety of printed patterns and inlaid designs.

Cork Tile

Cork tile is manufactured by baking cork shavings and particles under high pressure. The resins of cork together with the interlocking of the cork particles hold the many pieces in a single mass. The cork is packed by hydraulic presses into strong molds and baked from seven to ten hours at 450 to 600 degrees F. By varying the time and temperature different shades of cork tile can be produced. Dark and light shades are employed in floors to give attractive patterns. Cork tile makes quiet, warm and resilient floors that are very durable.

Trade Statistics

The production of cork products in the United States has risen sharply during the past fifty years. The figures in the following table show this increase:

YEAR	VALUE	YEAR	VALUE
1899	$ 4,392,000	1929	$23,656,117
1909	5,940,000	1933	10,440,000
1914	7,875,000	1937	20,106,544
1921	12,965,256	1939*	19,305,054

* Latest United States Census of Manufactures.

The United States consumes more cork than any other country. To keep this nation supplied and to meet the requirements of other countries, the annual production of corkwood has increased notably in the past thirty years. In Portugal alone the quantity of corkwood harvested in 1936 (120,000 metric tons) was six times the quantity obtained in 1919 (17,969 metric tons).

Cork production in recent years is given in the following table*:

COUNTRY	YEAR	METRIC TONS
Portugal	1941	167,463
Spain	1941	70,000
Italy	1941	13,814
France	1941	13,500
Algeria	1939	33,172
French Morocco	1937	18,500
Spanish Morocco	1942	733
Tunisia	1938	4,516

* Compiled from: Cork Production and International Cork Trade, Ernst Palmgren, Int. Inst. Agri., Rome (1947).

Production of cork was low during the recent world war but is now regaining normal proportions.

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Utilization Abstract

Sugar from Wood. "By the use of a dilute sulphuric acid solution, the cellulose fraction in wood may be converted into a sugar solution. From this sugar solution, four main products may be obtained: sugar, largely glucose, commonly referred to as corn sugar, might serve as a raw material for further chemical processing; molasses, as high as 85 percent glucose, which might be used directly as a source of carbohydrate in stock and poultry feed or as a source of crude sugar; alcohol, which may be produced by the fermentation of molasses or of the crude sugar . . .; and a high-protein yeast feed grown upon the sugar solution."

These developments offer tremendous possibilities for closer and more profitable utilization of the enormous quantities of wood waste on lumbering operations, at sawmills and at wood manufacturing operations. In 1944 the logging waste alone of Douglas fir in Oregon and Washington was found to be 11 million cords or 30% of the total net standing volume of the original stand. The total quantity available from all sources for what might be called a "wood-saccharification" or "wood-sugar" industry is perhaps many times this amount.

This production of sugar, alcohol and protein feed-material from wood waste has been carried on experimentally in Springfield, Oregon, where the extracting plant, previous to its present shut-down for remodeling, produced and sold from wood-sugar, 50,000 gallons of 190 proof industrial alcohol. Its full potential capacity is placed at 1,000 gallons of alcohol per day. (*E. G. Locke, Chemurgic Digest* 7(2): 8. 1948).

Figs—*Facts and Figures of 1948*

In 1947 six varieties of Old World figs, cultivated on about 50,000 acres in California, produced 30,500 tons of dried figs, the largest crop on record for the State.

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Introduction

SOME thirty years ago (Condit, 1919), my account of "Figs, Facts and Figures" began as follows: "Of all the fruit crops being planted in California there is hardly one which is being so favorably considered as the fig. Business men and ranchers throughout the state are discussing fig possibilities, the choice of varieties, soils and locations for the orchard and the things to be avoided in planting and pruning young trees. The fig acreage has already been doubled and bids fair to be tripled by plantings of 1920". The boom was due to high prices for figs and fig products and to the activities of promoters who painted rosy pictures of the expected profits from bearing fig "gardens". A Fig Growers' Association was organized to handle and market the fruit delivered by its members. Three years later (Condit, 1922) I wrote: "Considering the comparatively small acreage and tonnage of figs at the present time and the many new products being developed, a bright future for the fig seems assured". With this brief introduction let us look more closely at the past and present status of the fig industry.

History

The common fig, a native of the Old World, was early introduced into Mexico and later into California. Gardens at the San Gabriel Mission in 1829 included numerous fig trees. The variety of fig grown at the Missions was undoubtedly the black fig now known as "Mission".

Near the middle of the nineteenth century settlers in California and local nurserymen began to receive cuttings and rooted trees of a considerable number of fig varieties from the eastern United States and from Europe. The White Adriatic was the most widely planted variety during the two decades following 1885, but the dried product lacked the tenderness of skin and flavor of the imported fig from Smyrna. The Yearbook of the United States Department of Agriculture for 1897 stated that the White Adriatic "has many points of merit, but the fact that its quality when dried is inferior to that of the imported dried fruit from Smyrna has resulted in several efforts to introduce and grow the Smyrna type of fig".

Cuttings of the true Smyrna fig were brought into California by the Evening Bulletin, San Francisco, by the Fancher Creek Nursery, Fresno, and by the State Board of Horticulture. The trees grew vigorously enough, but as the fruit invariably dropped when about the size of a marble, there developed a widespread suspicion that cuttings of some worthless variety rather than those of the true Smyrna fig had been secured.

It had long been known that the successful production of the Smyrna fig in Asia Minor and elsewhere was made possible by transferring fruits from the

caprifig tree to the tree of the Smyrna type at the proper time. This resulted in the carrying of pollen to the latter by a small insect known as the "fig wasp". By transferring pollen from the caprifig to the flowers of the Smyrna fig by means of a toothpick, George Roeding of Fresno proved to the skeptical in 1890 that pollination of the Smyrna fig is a necessary prerequisite to fruit setting. The following year, by using a glass tube drawn out to a fine point, he succeeded in getting 150 figs to set and mature excellent fruit. This and similar experiments by Dr. Eisen showed that caprification is not simply a superstitious practice of ignorant peasants, and interest was stimulated in the attempts to introduce the fig wasp, or blastophaga, into California. This was accomplished in 1899, caprifigs containing blastophagas having been shipped from Algiers by W. T. Swingle who was commissioned by the United States Department of Agriculture for this express purpose.

The successful introduction of the blastophaga naturally stimulated interest in the commercial production of the Calimyrna (California Smyrna) fig, a name suggested as the result of a $25 prize offered by George Roeding for the most distinctive name of the variety in California. Small orchards were planted by individual growers in several parts of the San Joaquin Valley, and a few larger plantings were made by promotion companies.

Botany and Classification

The common fig belongs to the mulberry family, Moraceae, and to the genus *Ficus* which includes more than 1200 species.

The fruit, called the "fig", is a fleshy, hollow receptacle bearing flowers on the interior surface. At the apex of all figs is an ostiolum, or mouth, which is usually more or less closed by scales. Within certain receptacles of most, if not all, species of *Ficus* are various species of insects whose larvae develop from egg to adult inside the individual flowers. When the blastophaga, or fig wasp, leaves the fig, it may be dusted with pollen if the staminate flowers near the ostiolum are mature at that time. Such pollen is carried to other figs into which the insects enter to oviposit, and pollination is thus unwittingly accomplished.

There are four general horticultural types of the fig: the caprifig having flowers with short-styled pistils; the Smyrna; White San Pedro; and the common types having flowers with long-styled pistils.

Caprifig Type. The caprifig, indigenous to southwestern Asia, is the primitive type of cultivated fig, and the three types of edible figs have undoubtedly evolved from it. The short-styled flowers of caprifigs are adapted to oviposition by the fig wasp, and receptacles of the three crops of the tree harbor the larvae, pupae, or temporarily the adults of this insect.

Pollination of the flowers of Smyrna figs with pollen carried to them by blastophagas from the June crop of caprifigs is called "caprification". Man modifies the normal life history of the blastophaga by placing mature caprifigs in fig trees of the Smyrna type, thus causing pollen-dusted blastophagas to enter Smyrna figs instead of caprifigs. The female insects, which generally lose their wings as they push their way between the scales of the ostiolum, crawl over the long-styled flowers in a vain attempt to deposit their eggs. Pollination is thus accomplished.

Smyrna Type. Figs of the Smyrna type mature only after pollination of their long-styled flowers and a resultant development of seeds. Without such stimuli the immature figs of both the breba and main crops usually shrivel and drop when about an inch in diame-

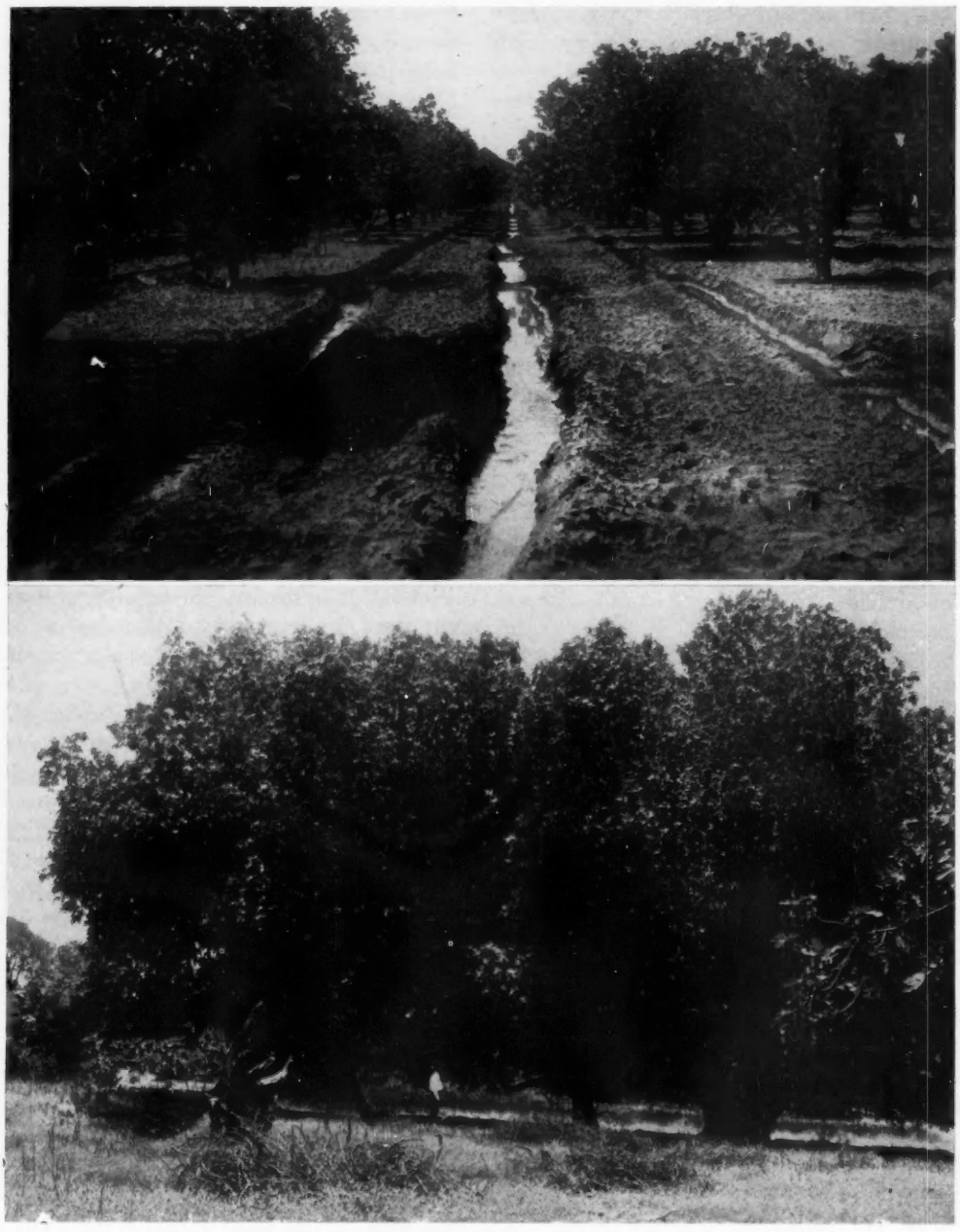


FIG. 1 (*Upper*). Furrow irrigation of a Calimyrna fig orchard.
FIG. 2 (*Lower*). Large Mission fig trees near Merced, Cal.

ter. Sometimes a few brebas develop without this stimulus. The fertile seeds account for the excellent quality of Smyrna figs.

Common Type. Figs of the common type do not require caprification in order to have the fruit mature. Varieties of this type are the Mission, Adri-

atic, Kadota and Turkey. Probably all common figs can produce fertile seeds if the flowers are caprified.

Varieties of Figs

Six varieties of figs are grown commercially in California, all of which originated in the Old World. They are, in the order of their commercial importance, Adriatic, Calimyrna, Kadota, Mission, Turkey and Brunswick.

Adriatic. The Adriatic is the principal drying fig of California, although the dried product is not of the highest quality. The trees are vigorous, very productive and thrive with little care. Second-crop figs are medium in size, variable but generally spherical or top-shaped, green, have light-strawberry pulp, strong fig flavor, and are rich and good when well ripened; seeds are numerous and hollow.

Calimyrna. The Calimyrna is identical with the principal drying fig of the Smyrna district. It is of high quality for fresh consumption locally, for distant shipment and for drying. The figs are large, onion-shaped, greenish or lemon yellow, and have amber or light-strawberry pulp and rich flavor; seeds are large, numerous and fertile.

Kadota. The Kadota is identical with the Dottato of Italy, where it is the principal drying variety. In California it has been planted mainly for fresh-fruit canning to which it is excellently adapted, although in recent years large tonnages have been dried. The figs are of medium size, globular or oval, yellowish green to lemon yellow when mature, and have an amber seedless pulp, sweet but somewhat lacking in character.

Mission. The Mission is an excellent fig, both fresh and dried, but the black color is objectionable to the baking trade and to eastern dried-fruit markets. The brebas (first crop) are large, pear-shaped, purplish black and have light-strawberry pulp and sweet rich flavor. Second-crop figs are medium-sized, oblong or pear-shaped, black with purplish bloom; the pulp is light strawberry with a pronounced but rich fig flavor; seeds are fairly numerous and hollow.

Turkey (Brown Turkey). The Turkey fig is best known in the Coachella Valley and in the vicinity of Los Angeles for its heavy production of large figs for the fresh-fruit market. It is practically worthless as a dried fig, and on account of its susceptibility to souring is seldom grown in the San Joaquin Valley. Second-crop figs are large, oblique bell-shaped, purplish black to reddish purple, and have light-strawberry pulp hollow at the center, and flat or insipid flavor.

Brunswick (Magnolia). The Brunswick fig, long grown in England, is characterized by narrowly lobed leaves, especially in the foliage of sucker wood. It has long been grown in Texas as a canning and preserving fig under the name of "Magnolia". Individual trees are common in California dooryards, but under the same conditions are much less vigorous and productive than the Kadota. The brebas are very few in number, large, reddish brown, with light-strawberry pulp. Second-crop figs are medium, spherical or top-shaped, reddish brown, and have amber seedless pulp and sweet flavor.

Figs for Home Orchards. There are a few other varieties worthy of trial for certain purposes or districts. Osborn is of especially good quality around San Francisco Bay and along the coast. The Celeste, a small violet-purple fig grown to some extent in Louisiana for preserving, is also good for that use in parts of this State.

White Genoa is a large yellowish-green fig which does well in some coastal districts but has no place in warm interior valleys. White Marseilles bears two crops of greenish-yellow figs of fair

quality in such a climate as Riverside, but can hardly compete with better varieties. Verdal Longue produces few if any brebas, but a very prolific second crop of green figs continuing to mature late in the season.

Fig Districts in California

The largest commercial plantings of figs in this State are located in the San Joaquin Valley, three fourths of the acreage being in the five counties of Stanislaus, Merced, Madera, Fresno and Tulare. The concentration of over 30,000 acres of figs in this area is due to the climatic factors of hot sunny days and low humidity which favor sun-drying of the crop and the production of good-quality fresh fruit for distant shipment and for canning.

In the coastal districts farther south fig orchards and individual trees usually produce excellent fresh fruit for local consumption.

Extensive plantings of the Kadota fig during the past few years have emphasized the fact that the areas in which fig culture can be prosecuted successfully have rather definite limits. Some decidedly unfavorable districts for fig culture are: those in which fall, winter or spring frosts kill back young trees severely year after year; those where the soil is salty, and saline water only is available for irrigation; those having light sandy soils infested with nematodes; and excessively windy sections.

Climatic Considerations

Frost. The fig tree is a deciduous, subtropical native of arid, semidesert regions of the Old World where its successful culture is limited more by low temperatures of winter than by the high heat of summer.

Young fig trees are very susceptible to frost injury. Experience has shown that there are three seasons when serious frost damage may occur: the fall season during October and November while the foliage is still green; the dormant winter period; and the season of early spring when the new growth is appearing. Dormant fig trees can be expected to withstand winter temperatures of 15° Fahrenheit without injury, but usually suffer at temperatures lower than this.

Heat and Humidity. Figs for preserving or canning are being produced in regions of summer showers and of a fairly high humidity. The production of dried figs is most satisfactorily accomplished in regions having long sunny days and a relatively low humidity. The vigor or health of fig trees can be influenced by cultural methods, especially by irrigation, so that they can withstand extremes of heat without serious injury to the quality of the maturing fruit.

Other Climatic Factors. Wind is not an important factor in fig culture, as far as the tree itself is concerned. Gentle breezes during the drying season are welcome, since they favor proper maturing of the fruit. Windy weather during the season of caprification may seriously interfere with the normal flight of blastophagas and result in a poor setting of figs of the Smyrna type.

Rains at the time of caprification are unwelcome and are especially serious during the drying season when figs may be either completely ruined or considerably injured in commercial quality.

Soils

Fig trees in California thrive on a wide range of soils. Trees in sandy soil commonly become unhealthy and unprofitable on account of root knot caused by nematode worms which are more prevalent in sandy than in clay soils. Excellent Adriatic orchards are found on a very heavy, sticky clay soil at Merced, with a hardpan about 28 inches beneath the surface. Some of the best

FIG. 3 (*Upper*). Dormant fig trees, Adriatic on left, Calimyrna on right.
FIG. 4 (*Lower*). Fresh Calimyrna figs as they are picked for market.

Mission fig orchards are located on deep, rich, river-bottom soils having an abundant moisture content. Deep clay loam soils are best for the culture of fig trees, but during the first few years vigorous tree growth may occur in such soils at the expense of fruitfulness.

Production of a uniform growth or

condition of fig trees on the leveled hogwallow type of hardpan land is difficult on account of the varying depth of the surface soil, but can be obtained by thoroughly blasting the hardpan and excavating the tree holes.

Propagation and Culture

Fig trees are so readily propagated from woody cuttings that no other method of propagation is considered in a commercial way. The cuttings are made during the pruning season, preferably in January or February, the brush being worked up as rapidly as possible to prevent drying-out of the wood. The bundles of cuttings are placed butt end up in a well-drained trench or on the surface of the ground and covered several inches deep with a sandy soil, care being taken to prevent air pockets by sifting the sand thoroughly between the cuttings. Planting in the nursery is done as soon as the ground can be prepared properly, which is generally about March 15. Planting should be followed immediately by an irrigation, and soil moisture should later be kept sufficient to maintain a steady growth of the young trees.

The successive steps in the establishment of a commercial fig orchard are: leveling the land, installing an irrigation system, locating or spacing the tree holes, preparation for planting, selection of nursery stock, planting, care of the young tree, intercropping. These operations are not essentially different from those used with other deciduous fruit trees and will not be detailed here.

It is important to note the fundamental differences between the fruiting habit of the fig and that of most other deciduous fruits. The peach tree, for example, bears one crop of fruit on wood of the previous season's growth. The fig tree normally bears two crops each year, the first crop appearing on wood of the previous season, the second crop on new wood of the current season's growth. The fruiting habits of different varieties of figs differ to some extent, and pruning methods which apply to one variety cannot be successfully practiced on certain other varieties. For instance, the Mission tree is notably unproductive under a system of very heavy pruning or stubbing-back of branches, while trees of the Turkey and Kadota usually produce bountifully under such a pruning treatment.

There is little justification for any pruning of young Adriatic trees except the removal of lower, spreading branches and a certain amount of thinning of the interior branches where they become too thick.

Annual or biennial pruning throughout the top of mature Adriatic trees obviates the necessity of heavy stubbing-back as the result of sunburned branches. The aim is to promote the production of new vigorous wood and to prevent the accumulation of a dense growth of short weak twigs.

The Mission tree usually develops into a tall much-branched tree which requires little pruning except an occasional thinning-out and the removal of interfering branches.

Calimyrna trees produce long upright branches without laterals on current season's wood. Vigorous branches eventually are inclined to become top-heavy with the weight of fruit and leaves, to bend down, and to become sunburned and decadent. The pruning problem of the Calimyrna grower is therefore to produce trees and branches which are capable of standing upright under future heavy crops. In deep rich soils young Calimyrna trees often produce upright branches several feet long without a single lateral. Either heavy winter pruning, or light summer pruning, may be used to shorten the intervals between laterals in such trees.

The pruning of bearing Calimyrna

trees consists of an occasional thinning-out and heading-back of the top in order to stimulate a constant succession of new vigorous wood on the main framework branches. Annual or biennial pruning of the top will help to prevent early decline of the tree and will encourage the production of fruit-bearing wood.

The Kadota fig is grown primarily for the production of fresh fruit and the trees are therefore trained low to facilitate economical harvesting of the crop. The objective is to secure a low, nearly flat-topped tree from which all the fruit can be obtained by pickers standing on the ground or on the main framework branches. In order to secure the flat top the inside branches are pruned shorter than the outside branches. The amount of wood left and the extent of the cutting depend upon the vigor of the tree. On one side of the tree a narrow space is kept open to make it easy for pickers and pruners to walk in to the center of the low-spreading tree.

In the fig districts of the Old World, where the rainfall is generally greater than in fig districts of California, orchard irrigation is the exception rather than the rule. Trees suffer, however, in dry seasons, and irrigation water would undoubtedly be an insurance against crop loss or injury. In California the irrigation of fig orchards is a necessary cultural operation except where the water table is high.

Methods of applying irrigation water to fig-orchard soils are not essentially different from those used in other deciduous orchards.

Spring plowing or disking to turn under the covercrop, either natural or planted, and light cultivation as often as necessary to destroy weeds are the usual practices. Clean culture and a smoothing of the surface soil in drying-fig orchards are desirable so as to facilitate picking up the fallen fruit.

Applications of nitrogenous fertilizers to bearing fig trees in the San Joaquin Valley have shown results in better vegetative growth. In some seasons such growth has not matured properly and has therefore suffered from early fall frosts. Moreover, there is a tendency for vigorous fig branches to produce large fruits more susceptible to splitting and souring. Some growers therefore practice spot fertilization, that is, application of material only to those trees which show by poor color of foliage or by weak twig growth their apparent need for a fertilizer.

The subject of caprification is a complicated one and we can discuss it only briefly. Perforated paper bags attached to the trees are commonly used as containers for caprifigs. Calimyrna figs are receptive to pollen when about three-quarters of an inch in diameter and remain receptive over a period of several days. It has been found in recent years that blastophagas carry into the fig not only pollen but the spores of injurious fruit diseases as well. The number of caprifigs distributed in Calimyrna trees should therefore be reduced to the minimum sufficient to insure a reasonable crop of edible fruit. It is generally better to obtain by caprification a light crop of clean figs than a heavy crop of figs inclined to rot on account of greater fungus infection. Results of a three-year caprification experiment at Fresno show that the use of one caprifig to 18 square feet of bearing tree-surface resulted in the largest average yields of passable Calimyrna figs. Fifteen pounds of figs were produced for each 100 square feet of bearing surface. Four distributions of caprifigs were made over a period of about 15 days.

Seedless Calimyrna figs have been produced without caprification by the use of a growth regulator in experiments conducted by J. C. Crane of the University of California, Davis, and Rene Blondeau of the Shell Agricultural Lab-

oratory, Modesto. The regulator, indole butyric acid, was sprayed on leaves and fruit at caprification time. The sprayed fruits grew to about the same size as the caprified ones but ripened about two weeks later. They were completely seedless but had about the same sugar content as caprified specimens. Experiments in 1948 will aim to find some growth regulator cheaper than indole butyric acid.

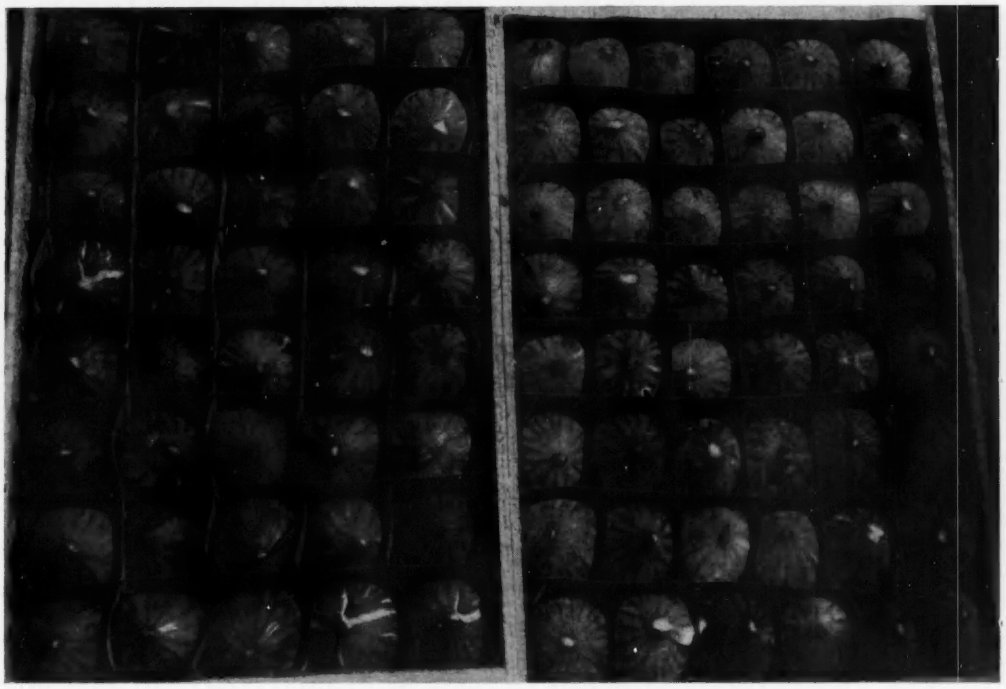


FIG. 5. Fresh Calimyrna figs packed in egg-cell filler.

Yields

Fig trees are regarded as being of producing age the seventh season after planting, but under favorable conditions young trees may produce appreciable crops as early as the fourth season in the orchard.

Calimyrna orchards in full bearing are generally credited with producing from 1.25 to 1.50 tons of dried figs per acre, and Mission or Adriatic orchards from 2.0 to 2.5 tons per acre.

Kadota fig trees are usually more precocious and heavier producers than are trees of other common-type varieties except the Turkey. Orchards three or four years of age may produce a few hundred pounds of fresh figs per acre, while those from five to seven years of age produce from 1.0 to 2.5 tons per acre. Older orchards are producing up to 5 and even 7 tons of fresh figs per acre.

Handling the Fruit for the Fresh-Fruit Market

The California fresh-fig market is supplied with Turkey figs from the Coachella and Imperial Valleys beginning about the first week in May; Mission figs start to ripen a few days later. Mission and Kadota brebas generally begin ripening in the San Joaquin Valley about the middle of June. Kadota, Mission and Calimyrna figs of the second crop mature about August first.

Except for a short period in July between the first and second crops, fresh figs are therefore obtainable more or less continuously from May until November, or even later in some districts.

Fresh-fig pickers usually wear cotton gloves as a protection against the acrid fig juice, carry a hooked stick to pull down branches, pick figs by twisting the neck loose or cutting it cleanly with a knife or pair of clippers, and deposit the fruit carefully in shallow boxes which are then stacked temporarily in the shade.

cessfully to large eastern markets in refrigerator cars by fast freight. The four-basket, square crate with each fig in a translucent tissue wrap has a very attractive appearance and carries well in transit. A rectangular flat with the figs placed in an egg-cell filler is also used. Packing is usually done by the grower in a shed adjacent to the orchard, and the packed boxes are assembled at a central plant for precooling.

Fresh-fig shipments to distant markets are largely handled by the California Fruit Exchange, the Pacific Fruit Ex-

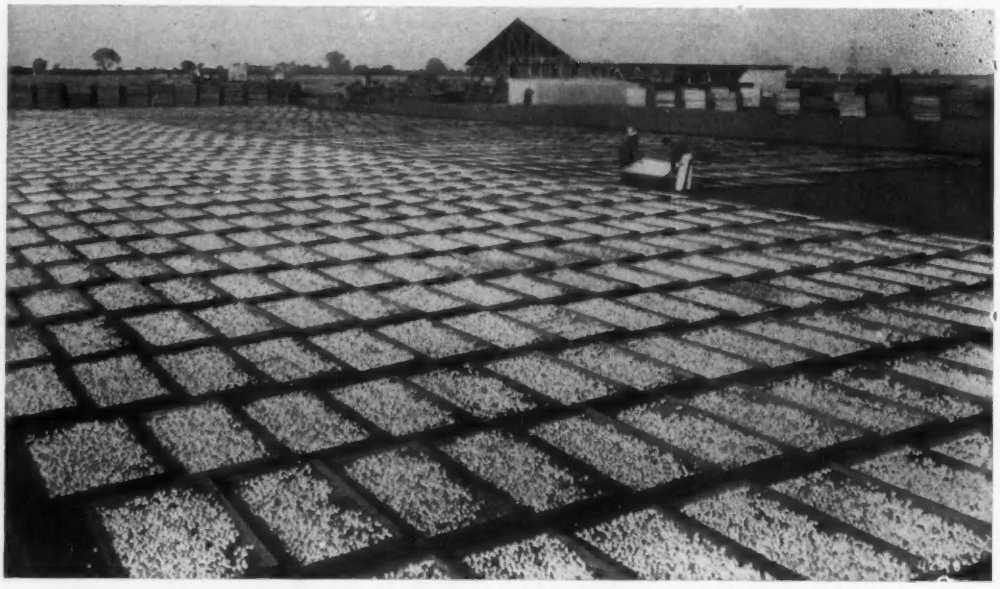


FIG. 6. Figs drying on trays near Fresno, Cal. (*Photo by C. P. Laval, Fresno*).

For local markets figs are usually packed in one-layer rectangular flats containing about six pounds of figs and having crosswise paper or cardboard fillers between the rows. During June and again in August and September, however, local market competition is keen. Less-than-carlot (l. c. l.), as well as full-express-car shipments to large eastern cities such as New York, have therefore come to be of considerable importance to the California fig industry. Kadota figs are being shipped suc-

press and other companies whose agents give instructions to growers and supervise the picking and packing.

Handling the Fig Crop for Preserving and Canning

The preserving and canning of figs in California on a large scale started about 20 years ago, both Calimyrna and Kadota figs being used. The Calimyrna canned fig is unsurpassed in flavor, richness and eating quality but meets a sales resistance on account of its softness,

seediness and large size of the fruit. The Kadota has therefore almost completely superseded the Calimyrna for canning purposes. The excellent canning qualities of the Kadota are due to the firm texture, yellow color, seedlessness and small uniform sizes of fruit rather than to superior flavor. Since the acreage and available tonnage of Kadota figs have increased, canners have become more particular as to the fruit to be processed, and some growers have been forced to find other outlets for their crop.

As with figs for fresh-fruit shipping, field agents of the handling concern more or less supervise the picking and advise growers as to methods of delivery. Pickers should go over the trees often enough to get a large proportion of the fruit in the condition desired by the canner. The figs are picked into shallow buckets, picking boxes or baskets suspended by a strap from the shoulders. The shallow lug boxes of fruit are delivered by growers to local canneries or shipped by truck or express overnight to more distant plants.

Frozen foods of various kinds are now receiving considerable attention, and the possibilities of distributing fresh figs in the frozen state have not been overlooked. In 1930 the Georgia Agricultural Experiment Station reported that peeled or unpeeled sliced figs frozen in a 35 per cent sugar sirup at a temperature of 0° Fahrenheit or higher proved to be a very satisfactory product. Investigations have shown that in all concentrations of sirup the Mission rated first, the Adriatic second, the Kadota third and the Turkey fourth. Frozen Calimyrna figs are of good flavor, but the seeds are large and the skin is tough. Fresh whole figs in 30 to 40 per cent sirup, frozen and held at 12°, are excellent in appearance, firmness and flavor.

Handling the Crop for Drying

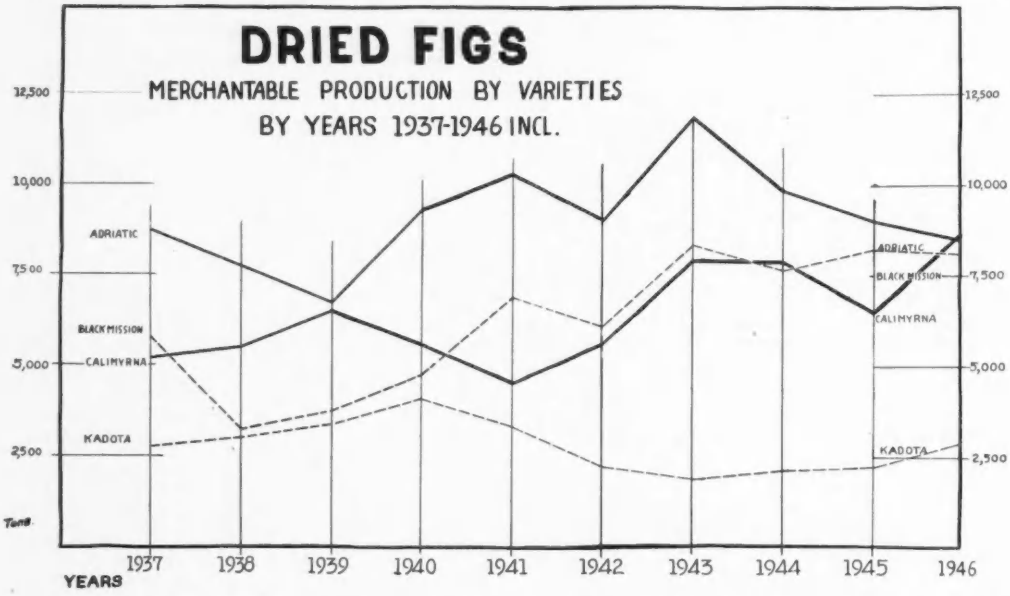
In Italy and some other countries fresh ripe figs are picked from the trees and dried in the sun, either whole or split in half. In California figs are allowed to become partially dried on the tree and to drop naturally to the ground. Figs left too long on the ground are unduly exposed to attack by insects and to the bad effects of overdrying. All figs on the ground, regardless of quality, are picked up and dumped into lug boxes holding about 40 pounds, payment being by piece work.

Sun-drying of figs is the method almost universally practiced in all countries. In most California districts Calimyrna, Mission and Adriatic figs are so nearly dried when gathered that they can be boxed loose immediately or finished on stacked trays; but those of the best quality are obtained by picking up frequently, drying on trays in the sun with occasional stirring or turning, and finishing on stacked trays. Kadota figs are handled like the Adriatic and are often classed with that variety in the market. The interior of a properly dried fig should have the consistency of a thick fruit jam or butter, and the skin a "kid-glove" softness and pliability. Sweat boxes, about $38\frac{1}{2} \times 26\frac{3}{4} \times 7\frac{3}{4}$ inches, are used for storing and equalizing the moisture in the fruit as well as for containers in which to deliver to the packing-house. Dried figs are also stored in large bins similar to those used for prunes and other dried fruits. The drying ratio of figs as normally harvested for drying is about $1\frac{1}{2}$ to 1. When picked at the firm-ripe stage, as for fresh shipment or for canning, the drying ratio is about 3 to 1.

Unless the grower is equipped with storage facilities by which he can effectively prevent insect infestation, he should deliver dried figs to the packing-

house as soon as possible after they are properly dried.

Packers after receiving figs from the grower, run the fruit over a shaker screen to remove foreign matter, then over large grader screens perforated with different-sized holes. This separates the figs into five commercial grades: Standard, Choice, Extra Choice, Fancy and Extra Fancy. Mission figs must be over $1\frac{3}{16}$ inches in diameter, Adriatic over $1\frac{5}{16}$ inches, and Calimyrna over $1\frac{3}{8}$ inches in diameter to qualify as Extra Fancy.



The packing of dried figs is a specialized process generally performed by experienced workers in plants equipped for the purpose. Fancy and Extra Fancy figs are often packed whole as pulled figs, or split open and flattened out as layer figs, or packed in various other special styles. Standard and Choice grades are sold in bulk direct to the trade or ground up into paste.

The processing of dried figs is fairly simple and can be done with ordinary kitchen utensils. Experience shows that immersion of figs in boiling water from one to three minutes gives excellent cleansing, rapid gain in weight and a uniform softening of the skin. The addition of salt (four ounces per gallon of water) gives a slight flavor attractive to most palates.

Pests and Diseases Affecting the Tree

Fig trees are commonly regarded as being singularly free from serious pests, a belief based upon the vigor of individual and orchard trees growing under favorable conditions. The grower is, however, often called upon to combat pests which if uncontrolled may either kill the tree or greatly limit its productivity

The root-knot or garden nematode is a minute worm which penetrates the fibrous roots and causes a beadlike swelling or knot to develop. Injured roots rot off, whereupon the plant produces new rootlets to replace those that succumb. No effective remedy is known when trees once become infested, but attempts are being made to find or develop rootstocks resistant to nematode attacks.

A species of scale insect, the Mediter-

ranean fig scale, has during the past 30 years become widely distributed in the San Joaquin Valley. The scale is very easily recognized—on the leaves by a yellowish discolored area under each scale, and on the maturing fruit by vivid-green spots which contrast conspicuously with the normal yellow color of the fig. Such figs are unmarketable for canning and fresh-fruit shipping.

Fig mites are often found in immense numbers on the bud scales and very young leaves of terminal twigs, sometimes causing leaf drop.

The Pacific red spider is a serious pest, especially of the Kadota fig tree. It injures the foliage and spots the fruit. At the first indication of infestation, treatment with oil sprays should be applied.

A distinct mosaic disease is found more or less commonly on leaves of practically all varieties, the Mission being especially susceptible. It causes malformations or dwarfing of leaves, premature leaf drop and even shedding of immature fruit. It has never been regarded as having commercial significance, but could hardly be controlled if it were desirable to do so.

Pests and Diseases Affecting the Fruit

Fresh figs of both crops are especially susceptible to injury by birds, the California house finch, or linnet, being mainly responsible. Estimates placing the loss in commercial orchards above 10 per cent are not uncommon.

Splitting of immature fresh figs is a serious fault of certain varieties such as the Calimyrna. It apears to be governed by atmospheric humidity or sudden changes in humidity, practically impossible to control.

Souring, which results in an immense loss of figs every year, is caused by the action of specific yeasts and bacteria on the internal saccharine juices of the fig. Investigation has shown that figs are internally sterile until they are entered by insects, after which they commonly become infected with yeasts, molds and bacteria; the general conclusion is that infection is limited almost entirely to insect transmission. The control of souring therefore appears to depend largely upon sanitary measures to eradicate the breeding material of dried-fruit beetles which are abundant in most fig orchards throughout the fruit-ripening season from about the middle of June to the first of November.

One of the most troublesome defects in dried Adriatic and Calimyrna figs is that which in the trade is called "smut and mold" or simply "mold". Smut is one form of mold in which the fungus forms a black, dusty mass inside the ripe or dried fig. Small insects, particularly thrips and certain species of mites, carry in the mold spores at an early stage when the figs are still green and before the eyes have opened.

Endosepsis or internal rot is caused by a fungus occurring in caprifigs and carried by the blastophaga into the edible figs. The control of endosepsis consists in removal of all caprifigs from the trees in March, cutting and splitting the figs into halves, submerging in a solution of Semesan for 15 minutes, drying as quickly as possible and placing in containers in the caprifig trees. This removal and treatment of caprifigs every year is necessary to ensure control of endosepsis. Endosepsis affects all varieties of figs but only when they have been caprified.

Utilization and Food Value of the Fig

Figs are consumed fresh, dried and canned, as well as in various prepared forms. Fresh figs are widely used in fig-growing districts, and with improvement of transportation facilities are becoming increasingly important in local and distant markets. Unfortunately the perishable nature of the fruit makes it

almost impossible to handle fresh figs on the retail market as cheaply as most other fresh fruits.

The bulk of the fig crop is consumed in the dried form. Fancy packs for the holiday trade provide an outlet for some of the better grades of dried figs, especially of the Calimyrna variety; actually, however, a relatively small percentage of the total California dried-fig crop enters into fancy packages. The baking trade takes the larger portion of the crop for the preparation of fig newtons, fig bars, *etc.*

Numerous analyses of fresh and dried figs have been reported. The sugar content of California fresh figs averages 15.5 per cent, although some show as high as 20.0 per cent. Calimyrna figs dried contain about 15 per cent water, 63 per cent sugar and 5 per cent fiber.

Analyses of Kadota figs show that the total sugar in the fresh fruit varies from 19.0 to 28.0 per cent, and in the dried fruit from 68.0 to 75.0 per cent. Analyses of Adriatic figs at different stages of maturity show that while the fruit is still green and firm but the eye fairly well opened, the percentage of moisture is 83.2 and the percentage of sugar 9.1; that when the fig is shriveling, with the pulp still red, there is 52.4 per cent water and 46.3 per cent sugar; while at the stage of completed normal drying in the orchard, the figs have 29.0 per cent water and 56.8 per cent sugar.

Figs possess in an unusual degree two important food qualities, a definite laxative effect and a high excess alkalinity of ash. The laxative effect is probably due to the bulk of seeds and fiber combined with some specific solvent present in the juice of the fruit. The medicinal preparations known as "sirup of figs" owe their laxative properties in large part to senna or to other drugs rather than to their fig content.

The chief nutritive element in dried fruits generally is sugar, one of the most valuable of the carbohydrates and certainly the most easily digested and assimilated of all. Dried figs have a considerably higher excess alkalinity than most other alkaline foods, and even fresh figs are more alkaline than are most fresh fruits and vegetables.

Figs have a high amount of calcium, the chief function of which is the building and maintenance of bone. Dried figs are rich in iron and also in copper, the latter having an important effect in stimulating blood production and therefore in preventing or curing nutritional anemias.

In the fig districts of the Old World both fresh and dried figs are commonly used for stock feed, the price of dried fruit for this purpose depending upon the prices for oats and barley. Even the leaves of fig trees are harvested when they are mature and almost ready to drop, and stored or sold for fodder. California substandard dried figs used for feeding dairy cows, other cattle, hogs or silver foxes are found to be an excellent carbohydrate food.

Some Economic Aspects of the Fig Industry

Acreage. The estimated fig acreage in California in 1946 was 33,302 acres of bearing and 2,510 acres of nonbearing trees. By varieties the acreage was as follows: black figs, 5,847; Calimyrna, 13,258; Kadota, 6,000; Adriatic, 10,153. It may be noted that there were 1,343 nonbearing acres of Adriatic in 1946, but only 39 of Calimyrna, indicating a very definite trend in favor of the former. Furthermore, considerable acreages of Calimyrna trees have been topworked to Adriatic, and more would have been changed over if dried fig prices had not been so high. The reasons for the growing disfavor of the Calimyrna may be summarized as follows: the extra labor and expense involved in caprification; the greater amount of spoilage at maturity and dur-

ing the drying process; lower yields and the probable smaller monetary returns per acre. Some fig orchards in marginal districts are being removed, while new plantings are being made in proven localities; thus the total acreage is being maintained or somewhat increased.

Production. The production of dried figs in California practically doubled during the decade beginning with 1928, in spite of the decrease in acreage during the same period. The average annual amount produced in the period 1926–1929 was approximately 13,000 tons, and during the years 1934–1937, 24,000 tons. There was a corresponding increase in the quantity utilized as fresh fruit. The 1946 crop of dried figs totaled 36,500 tons, about 8,800 tons consisting of substandard and cull figs. The largest crop of Calimyrna figs in history was produced that year, estimated at 8,545 merchantable tons; the total production of good Adriatic figs was 8,340 tons and of black figs 8,045 tons. Last year (1947) the crop of merchantable dried figs was the largest on record, 30,500 tons.

In 1922 about 1,400 tons of Calimyrna and 340 tons of Kadota figs were placed on the market. Since 1928 no Calimyrna figs have been canned. The output of canned Kakota figs reached a maximum of 942,080 cases in 1943. Last year 841,456 cases were canned. Kadota figs pack out from 55 to 60 cases to a ton of fresh fruit.

Competition. California canned figs compete in the consuming markets with Texas figs. However, this competition is more fancied than real, since the Texas output is comparatively small and Texas figs are packed mostly in glass and in a 35° sirup as a preserve.

The principal competition faced by the California industry has been from dried figs imported from Mediterranean countries. Imports into the United States reached a maximum of about 21,400 tons in the year beginning July 1, 1925, then declined, largely because of higher import duties and of more stringent pure-food requirements. The trade agreement between the United States and Turkey stipulates that the tariff on fig imports from that country be three cents a pound but that this rate shall apply only to those dried figs valued at seven cents or more a pound.

According to Foreign Crops and Markets (U.S.D.A.) for February 23, 1948, there was an 11 per cent increase in world dried fig production in 1947 over the five-year average of 1941–1945. During the 1946–1947 season Turkey was again the principal exporter, although Greece and Italy both exported some figs. United States imports totaled at that time 1,663 tons of which 921 tons were from Turkey, 574 from Greece and 161 tons from Italy. The estimated production of dried figs in six principal countries is as follows: Italy, 66,000 short tons; Turkey, 39,600; United States, 33,000; Greece, 27,800; Algeria, 21,000; Portugal, 11,600 tons. Spain is a very large producer of fresh and dried figs, but no reliable figures on acreage or tonnage are available.

Prices. The average wholesale price for dried figs in 50-pound boxes from 1895 to 1914 was four cents a pound for white figs and 3.4 cents for black figs. Following both world wars, prices for most dried fruits went to unprecedented heights. For the 1945 and 1946 crops California fig growers received up to 13 cents for good blacks, to 16 cents for good Adriatics, and to 24 cents for good Calimyrnas.

The Federal-State Market News Service has for several weeks past reported little demand for dried figs and few sales. The Bulletin for March 18 states: "The dried fig market remained dull with no outstanding developments reported. . . . Packers for the most part continued to follow the policy of making sales to the trade before purchasing

additional grower stocks. One lot of Adriatics was reported sold at 4⅞ cents per pound and some blacks at 4 cents''. This slump in grower returns is due to the reticence of packers to buy figs in the face of uncertain prices and to the carryover of dried figs from both the 1946 and the 1947 crops. This is in spite of the fact that the Federal government bought 6,000 tons of black figs for overseas relief. In May 1948 the the market situation showed improvement as the result of an announcement that the government had agreed to take 9,000 more tons of figs for European relief.

Payments to growers are made on a sliding scale based on the percentage of good figs delivered. Under the uniform Fig Buying Contract of the Dried Fruit Association of California, a delivery showing a test of 90 per cent or more passable Calimyrna figs at a basic price of seven cents per pound would bring the grower $140 per ton, while one showing an 80 per cent test would return him only $101.50 per ton. Growers therefore usually sort dried figs carefully before delivery to the packer.

California Fig Institute. On February 5, 1935, fig growers met at Fresno and organized the California Fig Institute, dedicated to the general improvement of the industry but not to packing or marketing dried figs or fig products. The Institute has, however, maintained a marketing-control program operating under the California Agricultural Prorate Act which provides for the establishment of a quality standard. Details of the Act are handled by a Dried Fig Proration Program Committee which sends out rules and regulations for each season's crop. All deliveries of dried figs testing not less than the minimum of passable figs permitted under the program (70 per cent since 1938) are classed as merchantable, and all lots testing less than that minimum are classed as substandard and diverted into by-products such as animal feed, alcohol, brandy and sirup.

On March 22, 1948, there was held at Fresno, under auspices of the Fig Institute, a conference of growers and packers to discuss marketing problems. Agreement was reached to authorize a committee of the Institute to draft a program to place the fig industry under a marketing agreement regulated by the State Department of Agriculture. A referendum vote will be taken of fig producers. If 51 per cent of the growers representing 60 per cent of the tonnage, or 65 per cent of the growers producing 51 per cent of the tonnage, approve the program, it will become binding on all producers. That is the situation facing the fig industry in April of 1948.

In 1946 the Institute appointed a Research Program Committee with the express purpose of undertaking investigations on fruit production problems. Dr. R. M. Warner became Director of Research, and a well-equipped laboratory was built in the vicinity of bearing fig orchards. Studies are being made in cooperation with other agencies of caprification, control of diseases and pests, irrigation and fertilization.

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Lignin—*A Botanical Raw Material*

This component of plant cell walls, which gives wood its woody nature, is disposed of as waste by the paper-pulp industries of the United States to the extent of more than three million tons annually. Economic utilization of it has long been a problem, and present day uses include conversion of it into vanillin for flavoring.

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Wood Waste as a Source

Everything we own is a gift of Nature. Whether it is our life, the food we eat, the cotton dress or the woolen suit we wear, or the car in which we ride, they are all presents of Nature. It provides us with the raw material which enables human ingenuity to produce our daily needs. With the continuing increase of the world's population and the right of every human being to live and to share in the gifts of Nature, we owe it a great debt of gratitude, and it is our duty to help Nature in the production of raw material.

The help we can offer Nature is manifold: by a sound economy of our natural resources, by improving the soil in order to enable it to produce more and, finally, by refinement of natural products—*i.e.*, by improving the quality of a material by scientific means in order to make it last longer and to make it more valuable.

Of all the natural resources in the world, wood is the most important. Coal, oil and other minerals are very important, too; they are, however, available only in a certain quantity. They will be exhausted after a limited period, depending upon the speed with which human beings waste them. With wood the situation is different. Although it may not be available in unlimited amounts, depending upon the amount cut yearly without a reasonable replanting, wood is reproduced yearly by Nature, at least to a certain extent. Wood is, therefore, a continuous source of a raw material. The years during and after a war, when waste of course is at its height, have shown that wood also is not available in unlimited quantities.

The amount of wood cut in the United States in 1944, the latest figure available, was 188,500,000 tons. Of these, 82.1 million tons, or 43%, were used as lumber, fuel-wood, pulpwood, ties, veneer, cooperage, mine timber, fence posts, shingles, *etc.;* 43 million tons were obtained as waste in the manufacture of the products just mentioned; and 65.9 million tons were left to rot in the woods as waste, or were wasted otherwise. The last two figures contain 8.6 million tons of pulp mill waste, consisting chiefly of what is called "lignin". Of these 8.6 million tons, about 5.2 millions, chiefly originating from soda and kraft pulp mill waste, were used as fuel for the recovery of chemicals to be reused in the production of pulp. This use of lignin cannot be considered a total loss because heat is required for the recovery of these chemicals and, as long as there is no better use for the lignin, it may as well be used as fuel and in this way save coal. The remaining 3.4 million tons of lignin, which came chiefly from sulfite pulp

mills, were drained into rivers and were therefore a total loss. Because on a percentage basis, this loss amounted only to 1.7% of the wood cut, one may ask the question: why worry about a 1.7% loss when over 33% is wasted in the woods? The answer to this question is simple. The waste left in the woods is not available for further use without additional costs and does not cause a public nuisance. On the other hand, the lignin which is obtained as a by-product in the pulp mills is included in the price paid by the mill for the wood, it is available in the mill without further costs for transportation, and its drainage into the water-ways in the form of calcium lignosulfonate causes contamination. Avoidance of pollution of rivers by sulfite waste liquor, however, is not the only reason why a more economical use for lignin is desirable. Lignin may serve as a raw material for other valuable products.

Wood is not the only source of lignin. Large amounts are annually produced on farms in the form of wheat, rye, flax, bean, soybean and rice straws, cotton and cornstalks, pea and potato vines. The amount of lignin yearly produced in these lignified materials is estimated to be about 30,000,000 tons on the basis of an average lignin content of 12–15%. When these materials are ploughed under or returned to the soil as manure, they should not be considered as waste unless there is a better use for them. No isolated lignin is available from these sources on a commercial scale.

Isolation

In the isolation of lignin, one has to distinguish between isolation on a laboratory scale and separation of lignin as carried out commercially in the production of pulp or in the wood saccharification process.

There are numerous ways to isolate lignin on a laboratory basis, which is done primarily for scientific research. A small amount of lignin, about 8–10% of the total lignin, can be extracted from wood by means of alcohol or dioxane at room temperature without the use of a catalyst. This so-called "isolated native lignin" seems to be unchanged as regards its chemical composition and properties and also in regard to its physical properties because no heat or other drastic treatment is applied. Isolated native lignin from spruce has a carbon content of 63.8%, hydrogen content of 6.2% and a methoxyl content of 14.8%. The last value agrees with that calculated by Hägglund on the basis of the lignin and methoxyl contents of the wood, taking into consideration that part of the methoxyl in wood which is combined with carbohydrates. Isolated native aspen lignin contains 63.2% carbon, 5.9% hydrogen and 19.5% methoxyl. The higher methoxyl content is caused by the presence of a syringyl group in the lignin molecule of hardwoods, as will be shown later. In all the other methods of isolation, the lignin is no longer identical with the protolignin as it occurs in wood, but has undergone more or less drastic changes, depending upon the mode of isolation.

The methods of isolation can be divided into two fundamentally different groups. Either the lignin is rendered soluble and in this way extracted from the wood, leaving the polysaccharides as an insoluble residue or—*vice versa*—the carbohydrates are converted into water-soluble products by hydrolysis or are extracted by means of a suitable solvent, leaving the lignin as an insoluble residue.

As Soluble Derivatives. There are several ways to dissolve lignin by converting it into soluble derivatives. The oldest method of extracting lignin by organic solvents is that discovered by Klason (8) who found that a large proportion of the lignin can be brought into

solution by ethyl alcohol in the presence of a small amount of hydrochloric acid which acts as a catalyst. This method was used later by many lignin chemists. In it the lignin is obtained as a condensation product with the alcohol, as is shown by a high alkoxyl content. Methanol spruce lignin, which is obtained by extracting spruce wood with methanol in the presence of 0.5% hydrogen chloride, has a methoxyl content of 21.0%, which corresponds to the entrance of two new methoxyl groups per lignin building unit of a molecular weight of about 840. Ethanol spruce lignin contains two ethoxyl groups. These new alkoxyl groups are present in an acetal-like form because they are split off again on treatment with mineral acids. The extraction of the total lignin in this way is prohibited by a simultaneous polymerization of another part of the lignin as a result of which it is rendered insoluble. The alcohol lignins are isolated by pouring the concentrated alcoholic solution into water, whereupon the major part of the lignin separates as a more or less brown powder, and another part remains in the aqueous solution because of its degradation into water-soluble products. In addition to the monohydroxy alcohols, di- and trihydroxy alcohols have been used.

A solvent which achieves the extraction of the total lignin is phenol. Phenol alone, even at high temperatures (100–110° C.), dissolves only insignificant amounts of lignin. Addition of a few drops of hydrochloric acid, however, immediately causes a condensation of the lignin with the phenol, as indicated by a change of color to dark violet brown. The phenol lignin formed is soluble in an excess of phenol and in other organic solvents, such as dioxane and acetone. The lignin is extracted quantitatively, leaving the cellulose and other carbohydrates in an insoluble but somewhat degraded pulp. The phenol lignin is isolated from the solution by removing most of the phenol by vacuum distillation and pouring the residue into a large volume of water. The phenol lignin thus obtained is not a uniform product but can be separated into two distinct fractions—the ether-insoluble phenol lignin, in which four phenol groups have entered the lignin molecule, and the ether-soluble fraction in which a considerably larger amount of phenol has reacted with the lignin. The mode of reaction which takes place between lignin and phenols is still unknown.

In addition to alcohols and phenols, organic acids, *e.g.*, formic, acetic and glycolic, can be used for the isolation of lignin. With strong acids, like formic, no catalysts are required. With weaker acids, such as acetic, small amounts of hydrochloric or sulfuric acid or magnesium chloride are added as a catalyst. The lignin is partially esterified in these reactions and dissolves in the reagent. The organic acid lignins are isolated by pouring the concentrated solution into water. Apparently no changes other than esterification occur in the lignin. An exception is provided by the thio acids. Whereas, in the methods just described, the lignin is converted into compounds soluble in the reagents used, it is also possible to condense the lignin with organic acids in which the new lignin derivative is not soluble but can be dissolved by other solvents. Such reagents are the thio acids. Holmberg (7) found that when lignified materials are heated with thioglycolic, thiolactic, α-thiobutyric, thiomalic or thiocitramalic acid in dilute hydrochloric acid three to four hours on a water bath, these acids react with the lignin with formation of lignothio acids which are insoluble in the reaction mixture. They are rendered soluble, however, by treating the thio acid-treated plant material with dilute sodium hydroxide at room temperature. From the alkaline extracts the

lignothio acids are precipitated on acidification with dilute mineral acids. Sprucewood treated in this way with thioglycolic acid in 2N hydrochloric acid gives a spruce lignotetrathioglycolic acid as a light cream-colored powder. Once isolated, this lignin preparation is soluble in dioxane and other organic solvents. Because it cannot be extracted with these solvents directly from the thioglycolic acid-treated wood, apparently a hydrolysis takes place during the extraction with alkali, thus rendering the lignin soluble in organic solvents. The four thioglycolic groups which are attached to the lignin molecule through their mercapto groups are not combined in a uniform way to the lignin, since they are partially split off on methylation with dimethyl sulfate and sodium hydroxide.

The ease with which thio acids, thiophenol and, probably, other thio compounds react with lignin is also shown by inorganic thio compounds, such as sodium bisulfite (Na_2SO_3) and sodium hydrogen sulfide (NaSH). Because these reagents are used in the processes in which lignin is obtained in large quantities as an industrial by-product, these methods of isolation will be discussed later, together with the isolation of lignin with alkali hydroxides.

Alcoholic sodium hydroxide is used for the isolation of lignin on an experimental basis. From straws lignin is extracted by this means in good yield at 100–120° C., whereas with woods a temperature of 160° has to be applied. The lignin is separated from the solution by distilling the alcohol and acidifying the aqueous solution with diluted hydrochloric acid. The alkali lignin obtained in this way as a light brown powder is, when carefully prepared, soluble in organic solvents. What changes, if any, take place in the lignin molecule during this treatment have not been definitively established.

As an Insoluble Residue. Whereas in the methods just discussed the lignin is rendered soluble, lignin can also be separated from the other plant components by dissolving out the polysaccharides. This is achieved either by hydrolysis of the carbohydrates to water-soluble sugars, or by extracting the former with suitable solvents.

There are two different ways by which saccharification of the polysaccharides can be carried out. The pre-extracted wood is treated, according to Klason, with 72% sulfuric acid for two hours at 15–20° C., the mixture diluted with water to give a 3% sulfuric acid solution and refluxed three to four hours to complete the hydrolysis. The lignin is then filtered, thoroughly washed with hot water, and dried. A lignin isolated in this way from spruce wood is called "Klason" or "sulfuric acid lignin" and contains about 64–65% carbon, 5.9–6.1% hydrogen and 15–16% methoxyl. The second way to hydrolyze the polysaccharides is based on the discovery by Willstätter and Zechmeister that cellulose is completely hydrolyzed to glucose when treated with supersaturated (42%) hydrochloric acid. When woodmeal is treated with this acid for two hours at 10–15° C., the mixture diluted with one-third of its volume of ice, kept overnight at room temperature and then diluted with the same amount of water, the lignin settles out as an almost black precipitate. It is filtered, washed successively with dilute hydrochloric acid and hot water, boiled with 1% sodium carbonate solution and washed until neutral with hot water. Lignin prepared in this way from spruce is called "Willstätter" or "hydrochloric acid" spruce lignin and has an elementary composition similar to that of a Klason spruce lignin.

A method in which the carbohydrates are removed, not by an acid hydrolysis but by an alkaline solvent for polysac-

charides, was developed by Freudenberg (5). He subjected pre-extracted spruce wood to a mild hydrolysis with boiling 1% sulfuric acid for two hours and then extracted it with a cuprammonium hydroxide (Schweizer's) solution. By alternate repetition of these treatments he obtained what is called "Freudenberg" or "cuoxam" lignin. Although it has approximately the same elementary composition as Klason and Willstätter lignin, cuoxam lignin is considerably lighter in color and is claimed to be more reactive than the acid lignins—*i.e.*, it is more closely related to lignin as it occurs in wood.

An entirely new method for the isolation of lignin by conversion of it into an insoluble residue is used by Purves (15) and his co-workers (13). They treat pre-extracted wood with a solution of sodium paraperiodate at pH 4 and 20° C., thus oxidatively cleaving the carbohydrate chain between carbon atoms 2 and 3. The oxidized polysaccharide is then hydrolyzed by boiling the wood with water at pH 6.5, leaving the lignin as an insoluble residue. Although the lignin may undergo some chemical changes, presumably oxidation rather than resinification, it is claimed that it resembles protolignin very closely. Periodate lignin gives a strong purple color reaction with phloroglucinol and hydrochloric acid, and dissolves almost completely in hot bisulfite solution. To what degree the lignin is oxidized by the periodate is still unknown.

The lignins isolated by these methods, although they still show the morphological structure of the wood, are no longer identical with protolignin. They have undergone more or less drastic changes by either polymerization or condensation or both, depending upon the severity of the conditions under which they were treated.

Technical Forms and Sources

Lignin is technically available in large amounts in two entirely different forms: in solution as a by-product of the pulp industry, and in a solid state as Scholler or Bergius lignin from the wood saccharification process. In the latter, the carbohydrates of the wood are hydrolyzed either with hot dilute sulfuric acid or with cold superconcentrated hydrochloric acid giving sugar solutions from which sugar is produced or is fermented to alcohol, carbon dioxide for dry-ice, and yeast suitable for human consumption. In both of these processes, the lignin remains in a more or less pure form as a solid, crumbly, dark brown mass which still shows the morphological structure of the wood. During this treatment with mineral acids, the lignin probably undergoes some changes caused by condensation or polymerization and loses part of its original reactivity. Scholler lignin was obtained in the United States in an amount of 115,000 pounds per day in the wood saccharification plant of the Willamette Valley Wood Chemical Company near Eugene, Oregon, where wood was hydrolyzed which otherwise would have been wasted. Since, however, this plant has been shut down because of unrentability, Scholler lignin is at present unavailable. It is possible, however, that, if a more valuable use of the lignin could be found which would pay part of the operation costs, the plant could be re-opened and could convert waste wood into useful products.

The lignin obtained from pulp mills in the form of waste liquors can be divided into three groups: sulfite waste liquor obtained from the sulfite pulping process, soda black liquor obtained from the soda pulping process, and kraft black liquor obtained in the kraft cooking process.

In sulfite waste liquor the lignin is

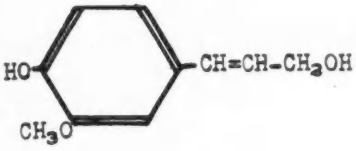
present as the calcium salt of a mixture of lignosulfonic acids which differ chiefly in their sulfur and methoxyl contents and their degree of polymerization—*i.e.*, their molecular weight. According to Schwabe and Hasner (13) and Ernsberger and France (1), the molecular weights of the lignosulfonic acids in a commercial waste liquor vary from 500 to 20,000, indicating that they are quite high compounds. In addition to these calcium lignosulfonates, sulfite waste liquor contains various sugars, *e.g.*, pentoses and hexoses, originating from readily hydrolyzable polysaccharides of the wood. Of these sugars, a part is fermentable and is utilized in Europe and in some mills in Canada for the production of alcohol and yeast.

In soda black liquor the lignin is present as the so-called soda or alkali lignin. This lignin is also changed as compared with native lignin. It is soluble in dilute sodium hydroxide but insoluble in water. It can be isolated readily in a solid state by acidifying the alkaline black liquor, causing the lignin to separate as a grayish-brown powder. As mentioned before, the lignin in soda black liquor is usually used as fuel for the recovery of valuable chemicals for their re-use in the pulping process. The amount of lignin present, however, is greater than that required for recovery of the chemicals. A few mills, therefore, isolate a part of the lignin by treating the black liquor with carbon dioxide. In this way alkali hardwood lignins, such as "Meadol" and "Tomlinite", are obtained.

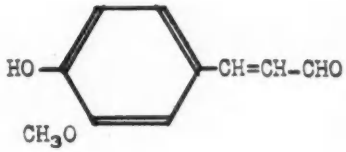
The waste liquor of the kraft pulping process contains a mixture of soda and thiolignin. Thiolignin is very similar to soda lignin but contains a small amount (1.5–3%) of sulfur, varying with the composition of the cooking liquor and the cooking conditions. The solubility of thiolignin is identical with that of soda lignin. The lignin in a kraft liquor can be isolated in the same way as the soda lignin. A lignin of this type isolated from pinewood is commercially available under the trade name "Indulin".

Chemical Structure

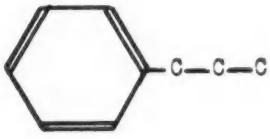
In order to make full use of a natural product as a raw material, its chemical structure and physical properties must be known. In spite of over 100 years of research, the structure of lignin is still unknown. It was in 1838 that Payen discovered that wood contains a component of high carbon content in addition to the polysaccharides. This component was called "lignin". Because of the tremendous amount of research which has been carried out since Payen's time, it is, of course, impossible in this paper to give a detailed picture of this work. Although no definite structural formula can be presented for lignin, there is evidence that lignin is built up of a certain type of building stones. It was over 50 years ago when the Swedish chemist, Peter Klason, believed that he had found some evidence that a close relationship exists between coniferyl alcohol (Fig. 1, I) or coniferyl aldehyde (Fig. 1, II) and lignin. These coniferin derivatives have in common the basic phenylpropane carbon structure (Fig. 1, III). In the course of further research, particularly by Erdtman, Freudenberg, Harris, Hibbert and Wacek, more and more experimental evidence was found which showed that, although the lignin building stone is not identical with the above coniferin derivatives, it is closely related to them. There is little doubt today that the major part of lignin is composed of substituted phenylpropane building stones. On alkali fusion of spruce lignin, moderate yields of pyrocatechol (Fig. 1, IV), protocatechuic acid (Fig. 1, V) and vanillic acid (Fig. 1, VI) are obtained in addition to formic, acetic and oxalic acids. Mild alkali treatment of



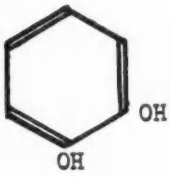
(I) Coniferyl alcohol



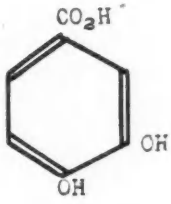
(II) Coniferyl aldehyde



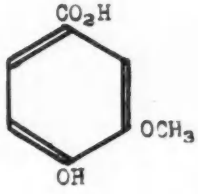
(III)



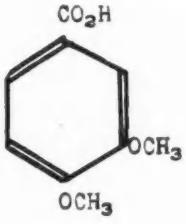
(IV) Pyrocatechol



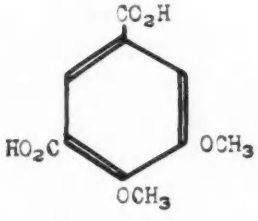
(V) Protocatechuic acid



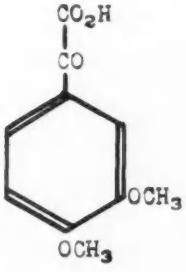
(VI) Vanillic acid



(VII) Veratric acid

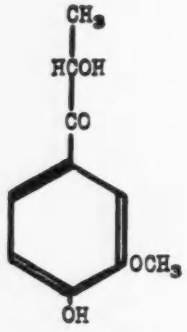


(VIII) Isohemipinic acid

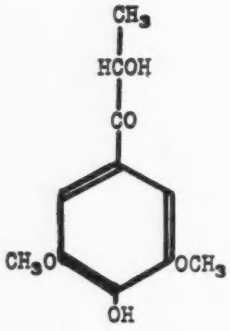


(IX) Veratroyl formic acid

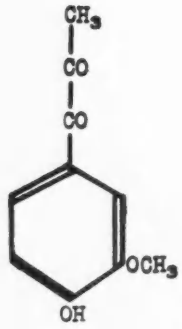
FIG. 1



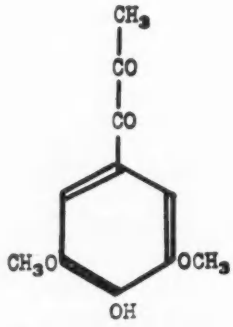
(X) α-Hydroxypropionylguaiacol



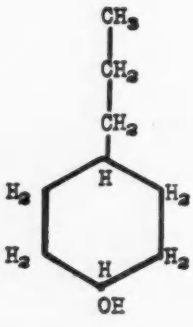
(XI) α-Hydroxypropionyl-3,5-dimethylpyrogallol



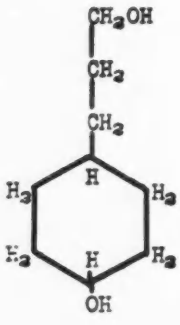
(XII) Vanilloylacetyl



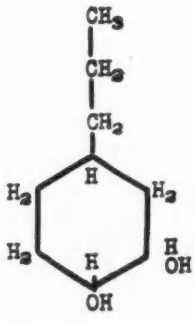
(XIII) Syringoyl acetyl



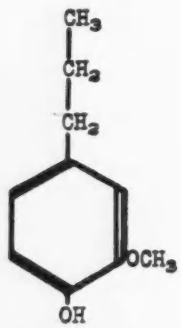
(XIV) 4-Hydroxycyclohexylpropane



(XV) 3-(4-Hydroxycyclohexyl)propanol

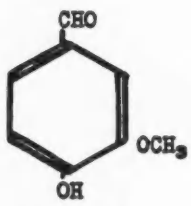


(XVI) 3,4-Dihydroxycyclohexylpropane



(XVII) 3-Methoxy-4-hydroxyphenyl propane

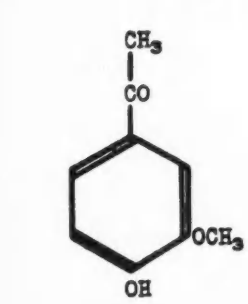
(XVIII) p-Hydroxybenzoic acid



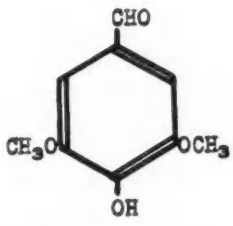
(XIX) Vanillin

FIG. 2

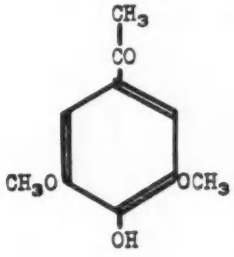
spruce lignin, followed by methylation and mild oxidation, gives veratric (Fig. 1, VII), isohemipinic (Fig. 1, VIII) and veratroylformic acid (Fig. 1, IX), whereas from hardwood lignin, the corresponding trimethylpyrogallyl derivatives are formed. On alcoholysis of soft- and hardwoods various guaiacyl and 3,5-dimethoxypyrogallolpropane derivatives, such as α-hydroxypropionylguaiacol (Fig. 2, X), α-hydroxypropionyl-3,5-dimethylpyrogallol (Fig. 2, XI), vanilloyl acetyl (Fig. 2, XII) and droxybenzoic acid (Fig. 2, XVIII) are obtained. Drastic oxidation of lignin gives oxalic, acetic and formic acids; mild oxidation of lignin in alkaline solution with certain metallic oxides or with nitrobenzene gives up to 25% vanillin (Fig. 2, XIX) in addition to some acetylguaiacyl (Fig. 3, XX) from spruce lignin, whereas from hardwood lignin syringic aldehyde (Fig. 3, XXI) and acetyl 3,5-dimethoxy-4-hydroxyphenyl (Fig. 3, XXII) are formed in addition to the guaiacyl derivatives.



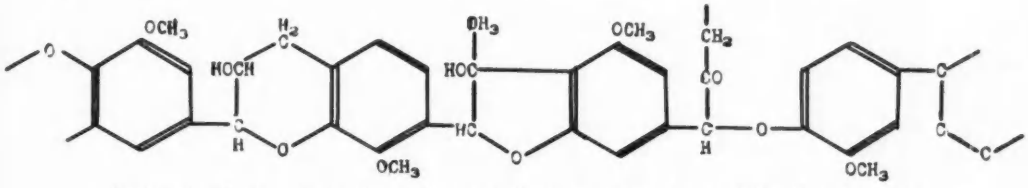
(XX) Acetyl-guaiacyl



(XXI) Syringic aldehyde



(XXII) Aceto-3,5-dimethyl-4-hydroxyphenone



(XXIII) Type of structural formula for lignin as proposed by Freudenberg.

FIG. 3

syringoyl acetyl (Fig. 2, XIII), are obtained. Hydrogenation of isolated lignin and of lignin in sulfite waste liquor and in wood in the presence of Raney nickel or copper chromite gives relatively high yields of cyclohexylpropane derivatives, such as 4-hydroxycyclohexylpropane (Fig. 2, XIV), 3-(4-hydroxycyclohexyl)propanol (Fig. 2, XV) and 3,4-dihydroxycyclohexylpropane (Fig. 2, XVI). Under milder conditions 3-methoxy-4-hydroxyphenylpropane (Fig. 2, XVII), protocatechuic acid (Fig. 1, V), catechol (Fig. 1, IV) and *p*-hy-

The question of whether lignin is built up of one type of lignin building stones only or of a series of different but similar types is not yet definitely settled. On the basis of experimental results, Freudenberg developed a scheme according to which the connection between the building stones may take place. The type of structural formula he proposed is shown in Fig. 3, XXIII. This formula is not considered to be the definite structure of the lignin molecule, but it shows in what manner the lignin building stones may be condensed with

each other to form the lignin molecule. This type of formula explains many of the reactions taking place with lignin, and the structure of many reaction products can be recognized.

Physical Properties

The physical properties of lignin are not very pleasant for the organic chemist. Lignins isolated by removal of the polysaccharides from lignified material are amorphous powders insoluble in any solvent at ordinary temperature. They are rendered soluble on heating with acetic acid or phenol in the presence of an acid catalyst to give the corresponding lignin derivatives, or with alkali to give alkali lignin. The changes which occur in the lignin molecule during these various treatments are still unknown. Lignin does not have a definite melting point and does not sublime or distill. Its heat of combustion is 6.277 kg. cal. per gram on an ash-free basis, which is about equivalent to that of peat and suggests its use as fuel. Lignin does not crystallize and shows all the properties of a high molecular compound.

Disposal and Utilization of Pulp Waste Liquor

Sulfite Waste. Because, as already mentioned, the lignin in waste liquors from soda and kraft pulping processes is utilized as fuel in the soda recovery plant and no wood saccharification plant is in operation at the present time, the principal source from which large amounts of lignin are available is sulfite waste liquor. It is obvious, therefore, why most of the work on the utilization of lignin has been carried out with sulfite waste liquor. Hundreds of papers have been published on this subject and thousands of patents have been granted, but, in spite of this, no final solution of the problem has been found. One of the principal reasons for the efforts to utilize sulfite waste liquor is the fact that the present method of disposal, namely, discharging the waste liquor into waterways, causes more or less serious trouble. With large rivers of strong current, in which the waste liquor is quickly diluted and carried away, contamination is not so serious. With smaller waterways having a slow current, discharging of the waste liquor causes a serious pollution of the water and not only endangers the fish life by reducing the oxygen content of the water but also makes the water unsuitable for human consumption.

Many proposals have been made for the utilization of sulfite waste liquor. They are based on its two principal constituents, *viz.*, calcium lignosulfonate and sugars. Sulfite waste liquor of a normal cook contains about 11–13% solids, of which 55–60% is calcium lignosulfonate, 35–40% carbohydrates and 5% inorganic salts. The sugars and the calcium lignosulfonates differ greatly in their chemical and physical properties. Whereas the former in a pure state are crystalline compounds of definite composition and chemical structure, readily soluble in water and forming sticky solutions, the latter are amorphous, high molecular compounds of unknown structure, also readily soluble in water and forming colloidal solutions; in a pure state they are dusty powders.

In order to find a use for lignin, the chemist has two alternatives. Either he takes the lignin as available from the wood conversion plants and combines it with other chemicals through unknown chemical or physical reactions in the hope that some useful product will result, or, on the basis of the results of his scientific research he will convert the lignin by known and controlled chemical reactions into other valuable chemicals. It is safe to say that all attempts to utilize sulfite waste liquor, with the exception of the preparation of

vanillin by mild oxidation, are based on a hit or miss chance with little or no scientific background.

One of the main obstacles for an economic utilization of sulfite waste liquor is the fact that it is obtained as a relatively dilute solution. Any attempt to use it has to be preceded by a concentration process. This process requires not only the evaporation of large quantities of water but also special precautions, since sulfurous acid is liberated during the concentration and must be neutralized in order to avoid corrosion and scaling unless a special apparatus is used. Depending upon the particular purpose, either sulfite waste liquor, as such, or calcium lignosulfonate alone is used. In the latter case it must be separated from the other components. This is done on a commercial basis by the Marathon Corporation in Rothschild, Wisconsin. Here the calcium lignosulfonate is precipitated as its basic calcium salt by means of lime water and is available in the form of a dry fine powder. From the basic calcium salt the water-soluble calcium lignosulfonate can be regenerated readily by decomposing it with an equivalent amount of sulfuric acid and filtering off the calcium sulfate. By interaction of the calcium salt with sodium sulfate or magnesium sulfate, sodium or magnesium lignosulfate is produced, both of which are commercially available.

When sulfite waste liquor as such is used, it must be concentrated. There are several instances in which the total sulfite waste liquor is utilized, taking advantage of the adhesive properties of the sugars, and in which the calcium lignosulfonate probably plays the role of a protective colloid to prevent crystallization of the sugars and in this way increases their tackiness. Concentrated sulfite waste liquor is used as an adhesive in paper mills, and in a somewhat compounded form for laying linoleum and similar purposes. Concentrated sulfite waste liquor has partially replaced the more valuable pitch in the briquetting of powdered coal, peat and saw dust. It is found particularly useful in the briquetting of zinc ore to facilitate distillation of the zinc from the muffle furnace, whereby the lignin serves simultaneously as a reducing agent. The binding properties of sulfite waste liquor are further utilized in the ceramic industry where it is claimed that its addition increases the strength of bricks and other ceramic bodies, probably because of the dispersing effect of the calcium lignosulfonate upon the clay. Concentrated sulfite waste liquor is also used as a binder for foundry cores and foundry facing sands. Because of the colloidal properties of calcium lignosulfonate, concentrated sulfite waste liquor is found to be a good dispersing agent for the preparation of emulsions, such as road tar emulsions. The use of sulfite waste liquor as a dust binder on roads is based chiefly on its sugar content which, because of its hygroscopicity, acts in a way similar to calcium chloride. Pure calcium lignosulfonate has no dust-binding properties. Because of the high solubility of sulfite waste liquor in water, the dust binding on a road sprayed with sulfite waste liquor will last only until it is washed away by rain. The dispersing properties of calcium lignosulfonate are utilized by adding it to drilling muds, thus increasing the viscosity and density of the fluid which aids in the carrying of rock and sand particles to the surface. Sulfite waste liquor has also been recommended as an aid in ore flotation whereby the calcium lignosulfonate forms wettable coatings on gangue particles, thus improving the degree of dispersion.

In addition to these uses, there are some cases in which isolated salts of lignosulfonic acid are used. The addition

of calcium lignosulfonate prior to or during the grinding of clinkers and slag prevents aggregation of the particles which otherwise adhere to the grinding surface of the ball mill and reduce its efficiency. Addition of calcium lignosulfonate to cement and concrete mixes causes a better peptization and dispersion of the cement particles and thus improves the flow properties. Sodium and magnesium lignosulfonates are used as corrosion inhibitors and water softeners in boilers to prevent the scaling of the boiler tubes.

One of the greatest efforts has been made to utilize sodium or magnesium lignosulfonate as a tanning agent. It is interesting to note that the patent originally granted to Mitscherlich on the bisulfite cook of wood contained as its principal claim the preparation of a tanning agent. There is little doubt that lignin is structurally related to the nonhydrolyzable tannins. The attempts to convert lignin into a tanning material are therefore justified, although they have not yet led to a satisfactory solution. Relatively large amounts of lignosulfonates are sold to the tanning industry, although these salts as such are not satisfactory tanning agents. They serve, however, as valuable dispersing agents for vegetable tannins, and, since they combine also with the hide, they act as useful fillers. Innumerable attempts have been made to improve the tanning properties of the lignosulfonates by condensing them with other compounds, but with little success. There seems to be no doubt that a better knowledge of the structure of lignin will enable the chemist to modify lignosulfonic acid by chemical means in such a way that products are obtained with a structure similar to that of the higher polyphenols (such as the natural tannins) with satisfactory tannin properties.

The colloidal properties of lignosulfonate solutions, particularly the foam-forming properties of their alkaline solutions, suggest their use for the preparation of soap or other detergents. These attempts have met with little success and have no prospect of success in this country with its ample supply of cheap fats. Small amounts of sulfite waste liquor are further used in electroplating, as a basis for insecticides and fungicides, as lubricants, as dispersing agents for printing inks and as fertilizer. The manufacture of decolorizing or absorbing charcoals and of artificial graphite by carbonization of the solids from sulfite waste liquor under various conditions has been discontinued because of better and cheaper raw materials for such products. In spite of all claims, neither sulfite waste liquor nor isolated lignosulfonates can be used in the plastics industry without a complete chemical conversion.

And finally, though by no means least, is the conversion of sulfite waste liquor into vanillin, a phase of utilization that is discussed in some detail later in this paper.

Soda Lignin. The completely different properties of soda lignin and kraft or thiolignin make them suitable for purposes for which the water-soluble lignosulfonates are unsuitable. Incorporation of a soda hardwood lignin into the paste used for making lead battery plates increases the capacity and the life of the battery, and addition of thiolignin as a filler for natural and synthetic rubber lessens the tendency of the rubber to flow or to squeeze out under pressure. This property and the light weight and resistance of lignin to attack by most common solvents and acids make a lignin-filled rubber a good material for gaskets and stoppers. It is also claimed that lignin increases the abrasive resistance of rubber in tires. The presence of phenolic hydroxyl groups in soda and thiolignin and the

inherent resinous properties of these lignins should make them readily adaptable to uses in the plastics field. Protolignin is thermoplastic. This thermoplasticity is lost when lignin is isolated by means of strong mineral acids or with cuprammonium hydroxide solution. The soluble lignins are still thermoplastic, and it is claimed that phenol lignin is very suitable for making plastics. In times of emergency, soda and thiolignin may replace up to 50% of the phenol in phenolformaldehyde-type plastics without too great an impairment of their physical properties. With its lower content of phenolic hydroxyl groups—only one per lignin building unit of a molecular weight of about 840—it is a raw material inferior to phenol. In normal times, therefore, lignin cannot compete with phenol in the plastics industry.

Alkali lignin condenses with aromatic amines, phenols, aldehydes and many other compounds, but, in general, the use of lignin in the field of plastics does not offer too much hope for the solution of the lignin utilization problem. Other disadvantages of lignin plastics are their brittleness and their dark color. A better knowledge of the structure of lignin, however, may result in an improvement in this field.

Objectives of Further Utilization. The ideal utilization of lignin, as of any natural organic product, is, of course, its conversion into other valuable products, such as chemicals as starting materials for other compounds or as compounds for direct use. Lignin chemistry today is in about the same position as the coal gas industry was 50 to 60 years ago when large amounts of coal were converted into illuminating gas and hundreds of thousands of tons of coal tar were produced as a valueless byproduct until chemical science made its utilization possible. With coal tar this task was relatively simple because the tar consisted to a large part of individual chemical compounds; the principal task was to isolate these compounds in a pure form, to establish their structure and, finally, to use them as starting materials for highly valuable products. This systematic research ultimately led to the creation of the tar dyestuffs, one of the most important branches of the present organic chemical industry.

Vanillin. It is obvious that, with the huge amount of lignin available, a new industry could be created if it were possible to convert lignin into a few pure chemical compounds. The foundation for such a development has been laid in the production of vanillin from lignin. The discovery that vanillin can be made from lignin or, to be correct, from the lignin fraction in sulfite waste liquor, *i.e.*, from lignosulfonic acid, is not new. As early as 1898 Pollascek obtained an Austrian Privilegium (patent) in which he claimed that he could obtain vanillin by oxidizing sulfite waste liquor with ferric chloride. This took place at a time when knowledge of the structure of lignin was still almost nil. Six years later Grafe found that when sulfite waste liquor is heated with lime at 180° small amounts of vanillin are formed. Over 20 years later, in 1928, Pauly and Feuerstein (11) claimed in a patent that vanillin is obtained on mild oxidation of lignin as it occurs in mosses, grasses, straw, hemp, flax, esparto and wood, of materials such as peat, lignite and brown coal which originated from lignified materials, of lignin-containing waste liquors, and even of isolated lignin preparations such as phenol lignin. Ozone in acetic acid and chromic acid in acetic acid were recommended as oxidizing agents. A yield of two kilograms of vanillin from 100 kilograms of wood (corresponding to about 6% based on the lignin) was claimed.

At the same time Kürschner (9) carried out an extended investigation on

the formation of vanillin from sulfite waste liquor by heating the concentrated liquor with alkali hydroxides while varying the concentrations of the alkali, the ratio of alkali to sulfite liquor, temperature and reaction time. The alkaline reaction mixture was acidified and the vanillin extracted with ether in yields of five to ten per cent. Kürschner recommended his process for the production of vanillin on a commercial scale. This, however, was found to be infeasible because of the cost of concentrating huge amounts of the dilute waste liquor, the high cost of chemicals required, and technical and economical difficulties involved in the isolation of the vanillin from the reaction mixture. The high consumption of alkali, particularly by the carbohydrates in the waste liquor, makes this process uneconomical unless a plant for the recovery of the chemicals without additional costs is available.

Some of these difficulties have been overcome by the so-called Howard process of the Marathon Corporation. According to this process, the lignin fraction of sulfite waste liquor is isolated in a concentrated solid state by fractional precipitation with caustic lime. Upon neutralization of the waste liquor, as it is obtained from the digesters, to a pH of about 8.5, calcium sulfite is precipitated and is recovered and re-used for the preparation of fresh cooking liquor. On further addition of milk of lime up to a pH of about 11, the calcium lignosulfonate is precipitated as its basic calcium salt which is insoluble in water and can readily be washed free of carbohydrates and other nonlignin materials. This basic calcium lignosulfonate, which contains about 85% lignin, is then heated under pressure for two hours at 160° with a 10% caustic soda solution in an amount corresponding to 25% on the basis of the basic calcium lignosulfonate. During this treatment the calcium lignosulfonate goes into solution with partial desulfonation and splitting of vanillin. The latter, formed in 3–4% yield, is present in the reaction mixture as its sodium salt and is directly extracted as such from the alkaline solution by means of butanol. The solution, which contains the sodium vanillate in addition to small amounts of other phenolates, is freed of butanol by distillation as an azeotropic mixture. The residual aqueous solution containing the sodium vanillate is acidified with an excess of sulfur dioxide. In this way the vanillin is converted into the vanillin sodium bisulfite addition compound which remains in solution, while other phenolic compounds are precipitated and removed by filtration. The vanillin is regenerated from the solution by acidification with sulfuric acid and expulsion of the sulfur dioxide. The crude vanillin is isolated by filtration and purified by distillation in a high vacuum, followed by crystallization from water. The vanillin obtained in this way is chemically pure.

This process was put into operation in 1937 by the Salvo Chemical Corporation at Rothschild, Wisconsin, which obtains the sulfite waste liquor through a pipe line from the Marathon Corporation. The daily production of vanillin amounts to about 1,000 pounds.

A somewhat different process for producing vanillin from sulfite waste liquor but almost identical with that of Kürschner (9) was developed by Hibbert and Tomlinson (14) and put into operation by the Howard Smith Chemicals, Ltd., in conjunction with the Howard Smith Paper Co. at Cornwall, Ontario. In this process the sulfite waste liquor is used as it is obtained from the digester. It is mixed with sodium hydroxide to give a 12% caustic soda solution. This amount corresponds to about 200% based on the lignin present in the liquor. This strongly alkaline

solution is heated for 6 hours at 125° C. or for 2½ hours at 160° C. The alkaline reaction mixture is carbonated by means of stack gases, and the precipitated solid, chiefly desulfonated, partially degraded lignin, is removed by filtration. The vanillin is extracted from the clear filtrate with benzene by a countercurrent system. The benzene solution is concentrated by distilling off a part of the solvent, and the vanillin is purified via its bisulfite addition compound in a way similar to that used by the Salvo Chemical Corporation. The yield of vanillin is about 2.8 grams per liter, which corresponds to about 4.5% based upon the lignin component in the sulfite waste liquor.

In the commercial processes just mentioned for the production of vanillin, the yields, based on the lignin material present, do not surpass five per cent. It was, therefore, a great step forward when it was found simultaneously by Freudenberg and co-workers (3) and by Schulz (12) that, when sulfite waste liquor is oxidized by means of nitrobenzene as oxidizing agent in alkaline solution, the yield of vanillin is increased to 25%. These investigators found also that not only the lignin in sulfite waste liquor but also other lignin preparation, even the lignin as it occurs in plant material, gave high yields of vanillin. This discovery was not only of technical importance but also of highly scientific significance. It supports the old hypothesis of Peter Klason (8) that lignin is a condensation product of coniferyl and hydroxyconiferyl alcohols. This formation of vanillin from lignin and lignified materials is analogous to the well-known preparation of vanillin by an identical oxidation process of isoeugenol. Whether the latter reaction allows any conclusions to be drawn as to the presence of an isoeugenol grouping in the lignin molecule is still open to discussion.

It must be emphasized that, for the production of pure vanillin, lignin from coniferous woods only can be used. It was shown by Hibbert and co-workers (6), who applied Freudenberg's process to hardwood lignin that, with this lignin, syringic aldehyde or 5-methoxyvanillin (Fig. 3, XXI) is formed in addition to vanillin. The technical separation of vanillin from syringic aldehyde is not simple. The discovery of syringic aldehyde in the oxidation products of a mild oxidation of hardwood lignin gave further support to the presence of the syringyl group in hardwood lignin. In addition to nitrobenzene, other oxidizing agents of similar oxidation potential, such as certain metal oxides and *p*-nitrobenzoic acid, have been found to give good yields of vanillin.

The principal use of vanillin is in flavoring ice cream, candies, beverages and baked goods, in some perfumes and in cosmetics. The demand for these uses is covered by the present production. The sulfite waste liquor of the Marathon Corporation in Rothschild is sufficient to provide the Salvo Chemical Corporation with all the raw material needed to produce the world requirements of flavoring vanillin on a basis of a five per cent yield at $3.00 per pound. It is obvious that, by using the Schulz process, the production can be considerably increased if further uses for a low-priced vanillin can be found either as such or for conversion into other valuable chemicals of unique properties—*i.e.*, chemicals which cannot be replaced by cheaper products with the same properties.

In the commercial vanillin processes, not more than five per cent of the lignin is actually recovered as a useful product. This amount could be increased by using the Schulz process, but even then 75% of the lignin is still lost. In an attempt to convert the total lignin in sulfite waste liquor into simple compounds,

Freudenberg and co-workers (2, 4), particularly Lautsch (10), carried out a systematic study of the hydrogenolysis of lignin. When Scholler lignin, previously impregnated with finely divided nickel, is slowly carbonized in a hydrogen atmosphere, chiefly aromatic compounds—namely, 5.5% phenol, 1.1% *p*-ethylphenol, 3.9% guaiacol, 7.1% *p*-creosol, 1.6% *p*-ethylguaiacol, 0.7% toluene, 0.5% *o*-ethylanisol, 2.0% *p*-homoveratrol, 0.5% *o*-ethylguaiacol, 1.3% isoeugenol, 2.9% pyrocatechol, 1.1% homopyrocatechol, 0.5% *p*-propylpyrocatechol, 10% phenols boiling at 135–180° C./0.03 mm., 0.5% methanol and ethanol, 0.2% methylcyclopentanol, 0.5% cyclohexanediol, and 2% higher boiling products, or a total of 41.9%—are obtained. A charcoal impregnated with nickel and suitable as a hydrogenation catalyst remains as a residue. When lignin is hydrogenated in solution, as was carried out by Harris and Adkins, hydrogenation of the aromatic ring takes place before the side chains are split off, rendering the latter more stable toward hydrogenolysis and giving cyclohexylpropane derivatives, such as Fig. 2, XIV–XVI. The presence of alkali delays the hydrogenation of the aromatic rings and favors the cracking and hydrogenolysis of the side chains. These conditions were applied by Lautsch to sulfite waste liquor. Using temperatures of 340–360° C. and high pressures, solid lignin and waste liquors are hydrogenated without catalysts, giving 15% phenols and 40% neutral compounds free of methoxyl groups. The latter are split off as methyl alcohol which in the alkaline solution takes part in the reaction as hydrogen donor and is dehydrogenated to carbon dioxide. When this property of alcohols is utilized and ethyl alcohol is added to the hydrogenation reaction mixture, up to 70% to 80% of neutral hydrogenation products are formed. Because the shipment of dilute sulfite waste liquor is uneconomical, any commercial process utilizing sulfite waste liquor must be carried out in conjunction with a pulp mill, as is the case with the two vanillin plants now in operation.

Summary

In reviewing the present state of lignin research and of utilization of lignin, one must admit that, although research has gone on for years all over the world and some progress in the elucidation of the structure of lignin has been made, no progress of any great importance has been made in the utilization of lignin, in spite of all the irresponsible newspaper publicity. The only exception is the discovery by Schulz and Freudenberg who found that high yields of vanillin can be obtained on mild alkaline oxidation of lignin. This discovery is not the result of hit and miss experiments in order to find a use for lignin, but is the result of systematic scientific research carried out in the hope of obtaining a contribution to the elucidation of the structure of lignin. This discovery is a typical example of how systematic scientific research may lead simultaneously to a process by which a hitherto worthless waste material can be converted into a highly valuable product. It alone, however, will not solve the problem. As mentioned in the introduction, lignin as a part of wood and other plant materials is the only organic raw material which is regenerated in practically unlimited amounts. Today it may be an undesirable liability; tomorrow it may be our most important, if not our only, organic raw material. The earlier we learn its structure, the earlier we may find a use for it by improving a material which is a gift of Nature.

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Utilization Abstract

Corn Products. Eleven companies having 13 factories in the North Central States comprise what is commonly referred to as the "corn-refining industry". This industry in recent years has bought more than one-sixth of all corn leaving farms and more than one-third of the quantity shipped to Corn-Belt markets. In the year ending September 30, 1947, the corn refiners paid about $250 million to United States farmers for about 140 million bushels of corn.

"The basic objectives of the corn refiners have been, first, the extraction of the various parts of the corn kernel in as many forms as possible, and second, the merchandising and application of these products to meet human and industrial needs.

"The manufacturing process accomplishes the separation of the major parts of the corn kernel—the starch germ, fiber, and protein—by the use of water as a suspension medium. A triumph of mechanical and chemical engineering is the process of converting corn of widely varying quality into many highly standardized commercial products which can be depended upon to do the same task in the same way, day after day and year after year. The main product of the process is cornstarch; the byproducts are feed and oil".

Cornstarch not only is marketed as such but is the raw material for conversion into modified starches and many important refinery products, principally syrup and sugar. The latter is accomplished by incomplete hydrolysis of the starch into various syrups containing different proportions of the edible dextrine or prosugars, maltose and dextrose; or by complete hydrolysis of it into white, crystalline dextrose. This process of hydrolysis is basically the same as takes place in the human digestion of starchy foods. The corn syrup is put on the market also as a fine, white, free flowing, hygroscopic, water soluble powder, commercially known as "corn syrup solids".

About two-thirds of the above mentioned 140 million bushels of corn went into corn sweeteners and one-third for starch as such. That year about 2,000 million pounds of corn syrup were sold. About 97% of it found its way into a multitude of food uses; tobacco products manufacturers were the principal non-food users. Over 125 different uses of corn sweeteners, as the sugar and syrup derived from corn are known, are catalogued in one of the publications of the Corn Industries Research Foundation.

This great utilization of corn syrup has come about only after the industry successfully combatted much public prejudice against the syrup and dextrose as sweetening agents, a prejudice which under the pure food law of 1906 regarded a product as misbranded or adulterated if it was sweetened or preserved with corn syrup. (*F. J. Hosking, Chemurgic Digest* 7 (4): 11. 1948).

Datura Innoxia—*A Potential Commercial Source of Scopolamine*

The drug scopolamine is important, among other uses, as a pre-anesthetic in surgery and childbirth, in ophthalmology and in prevention of motion sickness. Datura Metel of Asia and Africa has been regarded as the best source of it, but a pharmacognostic study, reported here, indicates that D. innoxia of Latin America is a possible industrial source.

GEORGE HENRY GERLACH

Vick Chemical Co.

Introduction

THE subject which forms the basis of this paper was suggested by Dr. Franklin J. Bacon, Professor of Botany and Pharmacognosy at Western Reserve University and Director of the Medicinal Plant Garden at the Squire Valleevue near Cleveland, Ohio. Dr Bacon has made a detailed study of all of the factors attendant to the cultivation of *Datura innoxia* Miller, and plants have been grown each year since 1929. I wish to acknowledge here my indebtedness to Dr. Bacon for the encouragement, aid and facilities granted to me in this research.

The plant used in this work was cultivated in the Medicinal Plant Garden at the Squire Valleevue Farm. The seeds were originally supplied by Mr. A. F. Sievers of the Bureau of Plant Industry, Washington, D. C. According to Mr. Sievers, *Datura innoxia* seeds were first planted experimentally by the Bureau in 1922, when seed was secured through Mr. W. E. Safford, Division of Botany, from Montserrat, British West Indies.

Historical Background of the Genus Datura

The Daturas are woven in the lore, legends, history, religion and medicine of every land and of every people from prehistoric times to the present. The Asiatic "metel-nut" is the species that figures most prominently in history. Whenever found, the Daturas first appear conspicuously in symbolism and religious ceremonies, since they were early recognized for their hypnotic properties and were employed as poisons and intoxicants (103).

The metel-nut appears in Arabic, Persian, Hindoo, Chinese, Japanese and Sanskrit literature, and the Far Eastern lore of the Daturas goes further back than the written records. The early Greek writers refer to "Nux Methal" which is believed to be the Eastern Datura. In the middle ages the term "Hippomanes" was applied to the Daturas (55).

From the thorny fruit of the Daturas arose the name "thorn-apple"—German, Dornapfel; French, pomme epineuse; Dutch, doornappel. The name "Jimson Weed" is a corruption of the name "Jamestown Weed", the common name of the American species, *Datura Stramonium* L., noted by the early Colonists as growing near Jamestown, Virginia. From its unpleasant narcotic odor the plant was given the name "stinkweed".

The name Datura was given to the genus by Linnaeus, in which he Latinized

the East Indian name Dhatura. There are many species of the American Daturas, varying from herbs and shrubs to trees throughout the two continents, and an excellent description of the various plants has been given by Safford (107) who also made a study of the history of the genus.

Amid the ruins of the ancient people who once populated the southwestern portion of the United States there are found the seeds and seed pods of the Daturas, and their use as an intoxicant and hypnotic still prevails among the Indian tribes of Utah, Arizona and Mexico. Only one species of Datura—*Datura Stramonium* L.—is recognized by the Pharmacopoeia of the United States to the exclusion of other species of equal or greater worth. The despised Jimson weed, *Datura Stramonium* (102), assumed prominence during the last war, at which time, as now, the solanaceous drugs, especially Belladonna, became very scarce. It was found at that time that this plant was a valuable source of the essential drug Atropine, even as *Datura innoxia* is a still better potential source of the equally valuable drug Scopolamine.

Synonymy of the Daturas

A critical study of the genus Datura by Safford (106, 107, 108) in 1921, and confirmed in practically all of its essential details by an investigation by Timmerman (122) in 1927, revealed a great confusion in botanical literature in connection with the specific identity, as well as the origin of some of the most common species.

Some authors, for example, have called the Mexican species, *Datura innoxia* Miller, by the name *Datura Metel*, but the true *Datura Metel*, described by Linnaeus (74) in the first edition of his "Species Plantarum", was a species based upon the Asiatic metel-nut, or "jouz-methel", which was used as a narcotic by the Arabs, Persians and Hindoos long before the discovery of America and was described by Avicenna in the eleventh century.

Much of the confusion is due to the treatment which this genus received at the hands of Dunal in the first part of volume thirteen of de Candolle's Prodromus (XII, 1:543) in 1852, in which the name *Datura Metel* was transferred from the Asiatic plant above mentioned to an American plant described in 1768 by Miller under the name of *Datura innoxia*. Dunal amended Linnaeus' description of *Datura Metel* and referred to it as a plant collected by Berlandier in the vicinity of Victoria in eastern Mexico, undoubtedly distinct from the true *D. Metel* L., but identical with the pubescent white flowered *Datura innoxia* Miller, described from a type also collected in eastern Mexico. The latter species cannot possibly be identified with *Datura alba* Nees, as suggested by Dunal, as that species is the typical white-flowered variety of *Datura Metel*, and *Datura innoxia*, moreover, has its "stalks, branches and leaves covered with soft hairs"; this feature at once separates it from the true Asiatic *D. Metel*.

Likewise, C. B. Clarke in Hooker's Flora of British India (107) (IV: 243, 1885) ignored Linnaeus' references in connection with *Datura Metel* and applied this species name to a plant of American origin, citing as an example of the species an incorrectly labeled illustration by Sims in "Curtis' Botanical Magazine" (plate 1440), 1812, which on investigation proved to be the drawing of a plant grown in London under the name of *Datura innoxia* from seeds of American origin, identical with the Vera Cruz plant described by Miller (83) in 1768 under the latter name. Still another name, *D. guayaquilensis*, was given to the plant by Humbolt, Bonpland and Kunth in 1818, but this never came into common use.

Hence, according to both Timmerman (122) and Safford (108), *Datura innoxia* has been incorrectly identified, classified and studied under the name of *Datura Metel*, and the *D. Metel* Dunal, *D. Metel* Sims as well as *D. guayaquilensis* are all in reality *Datura innoxia* Miller.

To add to the confusion, *Datura innoxia* very closely resembles another plant named *Datura meteloides* by Dunal. *Datura meteloides*, an American species used ceremonially by the Mexicans, Zunis and California Indians, occurs in two marked color forms, one with white and the other with pale blue- or lilac-colored corollas, and Dunal's original drawings show that this plant differs from *D. innoxia* Miller in having smaller leaves, acute at both ends but neither cordate nor angular in outline.

Timmerman (122) discovered that the herbarium specimens of this plant in the British Museum and at Kew Gardens as well as the plant indicated by Asa Gray's (37) description of this species were really variant forms of *Datura innoxia* incorrectly labeled *Datura meteloides*. It is of interest to note that the specimen of *Datura innoxia* filed in the Smithsonian Institute was also incorrectly labeled *D. meteloides*, but the original name had been crossed out and corrected by Safford some years previous to Timmerman's findings in British herbarium collections. As a result, *Datura innoxia* has also been confused with *D. meteloides* D. C.

An additional form closely related to *D. meteloides* and still more closely to *D. innoxia* is *Datura discolor*, which like *Datura innoxia* also has a nodding fruit and a 10-toothed corolla. It can, however, be distinguished from both of its allies by its black seeds and larger flowers.

As a result of Timmerman's study of the nomenclature of the Daturas, her recommended revision of the British Pharmacopoeial Monograph for Datura Folia was accepted by the 1934 British Pharmaceutical Codex (8) and was changed to read as follows:

Datura leaf consists of the dried leaves and flowering tops of *Datura Metel* Linn. (Fam. Solanaceae), an annual plant indigenous to India, and also of *Datura innoxia* Miller, an annual indigenous to Mexico, now growing freely in India and cultivated in England.

The British Pharmaceutical Codex, under Datura Folia, states that it contains hyoscine which occurs to the extent of from 0.25 to 0.55%, and mentions that traces of hyoscyamine and atropine may also be present. That being the assay standard, it seems strange that an addition to the Codex should be made purely on the basis of botanical classification without a chemical investigation to determine whether or not *D. innoxia* met the alkaloidal requirements of Datura Folia.

The omission of *D. Tatula* from the U.S.P. X. (96) (was in the U.S.P. IX.) similarly appears to result from the work of the American investigator, Safford, who was of the opinion that *D. Tatula* should be regarded not as a separate species but simply as a variety of *D. Stramonium*, and since the official description of the U.S.P. now states that the stems present may vary in color from light greenish brown to purplish brown, it may be assumed that it is intended to include the leaves of *D. Tatula*.

Historical Background

Hernandez (55), the sixteenth century medical explorer who journeyed through New Spain, found in Mexico a plant called by the Aztecs "nacazcul", "toloatzin" and "toloache" which has since been designated as the *Datura innoxia* Miller. Hernandez properly described it as "having leaves clothed with soft hairy pubescense". He found this and other Daturas to be highly esteemed by

the natives medicinally and ceremonially, and, by reason of its trumpet-like flower, considered it as belonging among the morning-glories. This species, *Datura innoxia*, indigenous in Mexico and tropical America, was later introduced into the Canary Islands, southern Europe and India. It has been confused by many writers with the old world *Datura Metel*, but is easily distinguished from that species by the 10-angled limb of its corolla and the soft pubescence of its foliage and young branches.

Datura innoxia Miller was first botanically described and classified by Philip Miller (83) in the 8th edition of his "Gardener's Dictionary" in 1768. It is there listed as Datura No. 5. Miller's description was somewhat amplified in "The Gardeners and Botanists Dictionary" by Miller, corrected and revised by Thomas Martyn (82) in 1807. From the year 1812, when Sims figured the plant in "Curtis' Botanical Magazine" and incorrectly labelled it *Datura Metel* Linn., up to 1921, when Safford made his comprehensive survey of the Daturas, the nomenclature of the section of the genus "Dutra Bernhardi", which among others includes *D. Metel*, *D. fastuosa*, *D. innoxia* and *D. meteloides*, was hopelessly confused and *Datura innoxia* virtually lost its identity.

Safford (108) in the United States and Timmerman (122) in England have cleared up most of the difficulties and have traced many of the errors that were made back to their original sources. In the interim, however, it is undoubtedly true that some of the important phytochemical investigations made on the various species of Datura have been carried out on drugs incorrectly identified or classified botanically.

Datura innoxia has not been generally recognized in Pharmaceutical literature and texts. It was listed in the British Pharmaceutical Codex 1934 (8). It was merely mentioned in the 22nd Edition of the United States Dispensatory (19) as a result of the work of Hester and Davy (47), and was briefly described in Trease's "Textbook of Pharmacognosy" (126), but a search of the literature failed to reveal any other reference to this plant.

Description

The genus Datura, established by Linnaeus (74) with *Datura Stramonium* as its type, belongs to the family Solanaceae and to the tribe Dutereae which includes the closely allied genus *Solandra* of tropical and subtropical America. *Datura innoxia* Miller belongs to Section II of the genus, namely Dutra Bernhardi. Miller (83), in his "Gardeners Dictionary" (Ed. 8, Datura No. 5, 1768), describes it as follows:

This rises with a purplish stem three or four feet high, dividing into several strong branches. Leaves oblong heart shaped. Stems branches and leaves covered with soft hairs. The flowers come out at the divisions of the stalk and branches, standing erect; they are large, white; and are succeeded by oval fruit, covered with long soft innocuous spines, and opening within in four cells, full of brown seeds.

Datura innoxia is a rather large and coarse annual herb, branching somewhat freely, giving a bushy look to the plant. It attains a height of about three feet, its spreading branches covering an area almost as broad.

The leaves of *D. innoxia* are different in outline from those of *D. Stramonium* or *D. Tatula*. They are ovate, often somewhat cordate in shape, and average about 12 cm. in length by about 7 cm. across at the widest part. The margin of the leaves is entire or may show several slight indentations, and the apex is acute. They are densely pubescent. The leaves are dark green in color, the under surface being a somewhat lighter green than the upper, and the veins are very prominent on the lower surface.

The veins do not run all the way out to the leaf margin as in *D. Stramonium*, but instead stop about 1–3 mm. from the edge and are joined to one another by arches. The abundance of narrow, very acute, warty covering hairs on the densely pubescent leaves enables one to distinguish the plant from *D. Stramonium*, *D. Tatula*, *D. Metel* and *D. fastuosa*.

The root is long, thick and whitish, giving off many secondary roots. The stem is stout, erect and branching repeatedly in a forked manner, producing in the forks of the branches a single erect flower. The stems and petioles of *D. innoxia* vary from light green to dark green in color. They are densely pubescent and show one or more fairly deep furrows.

The plant flowers nearly all summer. The flowers are white, funnel-shaped, borne in the forks of the branches, about 8 cm. long. The expanded limb of the corolla is 10-angled and the corolla is 10-toothed. The flowers open in the evening for the attraction of night flying moths and emit a powerful fragrance.

The flowers are succeeded by large seed capsules of a green color, ovate-conical in shape, about 5 cm. long and 4 cm. wide, covered with numerous sharp spines. When ripe, this seed vessel opens at the top, throwing back four valve-like forms, leaving a long central structure upon which are numerous rough, light-brown seeds.

Like most other species of Datura, *D. innoxia* exudes a rank, heavy narcotic odor. This fetid "mousy" odor arises from the leaves, especially when they are bruised. The nature of this odorous principle is undoubtedly very similar to, if not identical with, that of *D. Stramonium* which was investigated by Sivolsbov (119).

The chief microscopical features of the leaves are the typical Solanaceous stomata (125) on both surfaces. The trichomes in *D. innoxia* are of three kinds: smooth or slightly warty long-stalked glandular trichomes terminating in a single spherical secreting cell; short club-shaped glandular trichomes; and warty trichomes, the basal cell of which is never more than 50 microns in length.

Cluster crystals of calcium oxalate and large crystalline masses of unknown composition occur in the mesophyll of the leaves. These crystals were investigated by Timmerman, but she was unable to identify the material. An examination of the chemical tests which were employed to analyze this crystalline material indicates that it is organic and nitrogenous, and in many respects it meets the requirements of an alkaloid, although Timmerman did not thus identify it.

An excellent and comparative histological study of the leaves, stems and seeds has been made on *Datura innoxia* as well as on the other closely related species of *Datura* by Timmerman (123, 124), and sectional drawings have been printed in the Pharmaceutical Journal. The distinguishing microscopic features of *D. innoxia* leaves are its characteristic trichomes.

Cultivation

Datura innoxia is not as easily cultivated as *D. Stramonium* (93), although it will flourish in various types of soil and can be grown commercially in a wide range of climatic conditions. The plants cultivated at the Squire Valleevue were grown in a rich clay loam in an open sunny situation.

Seeds may be sown in the open in April or May, in drills about three feet apart, covered to a depth of one to two inches and sown thinly as the plants attain a good size and grow freely from seeds in which germination has been aided and hastened by alternate freezing and thawing to weaken the seed coat.

This has been found to work more satisfactorily than preliminary treatment of the seeds with hydrocyanic acid gas, as suggested by Zanotti (135). Sievers (115), in the case of belladonna, also found that subjection of seeds to freezing temperatures accelerated germination and accordingly recommended fall planting, since that plant, like *D. innoxia*, has seeds which germinate very slowly and irregularly and, as a rule, do not show over 50% germination. He also found that treating the seeds with hydrogen peroxide was of some benefit, whereas immersion in sulfuric acid did not produce any material increase in germination (116, 118).

The young plants should be thinned out to a distance of 12 to 15 inches in the drill. About ten pounds of seed should be allowed to the acre. The soil should be kept free from weeds in the early stages, but the plants, once properly started, are so strong that they require little care later. If the summer is hot and dry, a good mulching of rotted cow-manure will produce larger and healthier plants.

Since *D. innoxia* transplants readily, it may also be raised from seeds sown in a hot-bed in February or March, or in April in boxes in a cool greenhouse, the seedlings, when large enough, being thinned out and transferred to flats in which they are grown with as much light and air as possible until June when they are planted in the open.

If grown for leaf crop, the capsules should be picked off as soon as formed, for in a wind the spines may tear the leaves. Some seed, for propagating purposes, should always be collected from plants kept specially for that purpose.

Koch (58) in 1919 directed attention to the fact that in *D. Stramonium*, if the stems of the plant could be utilized, the cost of labor in harvesting a crop would be only one-fourth or one-fifth of what it is where the leaves alone are gathered, since machinery for that purpose could be employed. As will be shown later in this paper, a critical examination of the alkaloidal content of the various parts of *D. innoxia* favorably indicates that the entire plant, either with or without the root, can be used, and it can therefore be harvested with a mower. The complete plants can thus be harvested economically, dried and ground ready for the extraction of scopolamine.

Datura innoxia may be harvested at any time from the appearance of the flowers until autumnal frosts. Indications are that the alkaloidal content is greatest at the height of the flowering period, and that is the best time to cut and dry the plants (98, 117). This will occur about early August, and the crop should be cut on a fine day in the morning after the sun has dried off the dew. The drug should then be carefully air dried as quickly as possible at a temperature of 50° to 60° C., since it has been demonstrated that *D. Stramonium* and *Atropa Belladonna* dried at this temperature retain their alkaloidal content without any significant change for five years or more. (80, 81, 84).

A satisfactory method of drying consists of stringing the entire plants on wires spaced at about three-foot intervals in a well ventilated shed. In this way overhead space can best be utilized and the drug will dry uniformly and completely in a relatively short time.

For the collection of seeds the thorny capsules should be gathered from the plants when they are quite ripe but still green. They should then be dried in the sun for a few days, when they will split open and the seeds can readily be shaken or sifted out. The pods can also be shucked mechanically at this stage. The seeds can then be dried, either in the sun or with the aid of artificial heat, preferably not in excess of 60° C. Kiln dried seeds are of no use for cultivation.

The dried ripe seeds are a dull brown

in color, flattened, reniform, wrinkled and marked with small depressions. Though ill-smelling when fresh, when dry they have a scarcely perceptible odor until crushed, but a bitter oily taste. They should not be stored in a damp place or they will mildew.

Preparation

The entire dried plant, with or without roots or fruits, should be ground in a Mead mill or limited drug mill to about a #20 mesh. The stems constitute approximately 40% of the total weight of the dried plant, and it will be found difficult to grind the stems much finer in one milling because of their tough fibrous nature. On the other hand, if the mill is set to produce a #20 mesh material, it will be found that much of the leaves, petioles, calices and flowers will be finer than #20 mesh powder.

This condition is fortunately very desirable because the bulk of the alkaloid is found in those parts of the plant, and, the finer they are ground, the more complete the extraction will be in the percolation process (11). The coarser particles of stem, as well as those from the roots, seeds and capsule spines, all of which are difficult to grind, will break up the fine powder in the percolator and will thus tend to inhibit packing, plugging or channelling of the menstrum. At the same time, these plant parts will also contribute to the alkaloidal extractive yield and are therefore superior to inert rice hulls, sawdust or sand which are customarily used to accomplish this purpose when percolating fairly fine powdered drugs.

Alkaloidal Constituents

Hester and Davy (47) demonstrated that the only alkaloid present in *Datura innoxia* Miller is levo-scopolamine, and based their conclusions on the melting points of the aurichloride and picrate as well as upon the specific rotation of the difficultly crystallizable alkaloidal base which they obtained.

Their assays showed that the plant contains from 0.394 to 0.713% levo-scopolamine, depending on the method of analysis used. Their work also indicated that the drug is an excellent potential source of this therapeutically useful alkaloid.

As stated before, no other references of chemical work of this type done on *Datura innoxia* Miller were found in the literature, and it is suspected that the confused nomenclature of the Daturas is in part responsible for this condition. The seeds from which the *Datura innoxia* was grown by F. J. Bacon of Western Reserve University were secured through W. E. Safford of the U. S. Bureau of Plant Industry from Montserrat, British West Indies, in 1921. It was stated in the "Inventory of Seeds and Plants Imported from January 1 to March 31, 1921", published by the Division of Foreign Plant Introduction, that,

It (*D. innoxia*) has recently been cultivated on the Island of Montserrat, British West Indies, as a source of scopolamine, an alkaloid with the properties of atropine.

It seems more than a coincidence that in 1924 an article entitled "*Datura Metel* from Montserrat" (Anon.) (18) was published in the Bull. Imp. Inst. (XXII, 134, 1924), and it is quite possible that the drug there described, because of its high scopolamine content, was in reality the same *Datura innoxia* Miller investigated by Hester and Davy.

Scopolamine Versus Hyoscine

The names "scopolamine" and "hyoscine" are now regarded as synonymous by most authorities, although this has not always been the case. The name "hyoscine" has in the past been applied to two or more distinct substances. It was first suggested by Hoehn and Reichardt (49) for the basic hydrolytic

product of hyoscyamine, now known as "tropine". It was subsequently used by Ladenburg (65, 66, 67) for an alkaloid stated to be isomeric with atropine, $C_{17}H_{23}O_3N$, isolated from the mother liquors of hyoscyamine. It is now generally held that Ladenburg was mistaken in his statement concerning the composition of this alkaloid, since it was found by Schmidt (113), Hesse (41, 42, 43) and others to be identical with scopolamine, $C_{17}H_{21}O_4N$, obtained by Schmidt from *Scopolia japonica*. Its structure was later elucidated by the work of Willstatter (132) and his students, and elaborated upon by Schmidt (114), King (56) and other workers (25, 98).

Although the name "hyoscine" has priority and is in commercial use, particularly in England, the name "scopolamine" is perhaps even more widely employed, especially in Germany and the United States, because of its greater accuracy. There is, however, a tendency to use the word "scopolamine" for optically inactive d-l-hyoscine (racemic scopolamine) which Hesse (42, 43) obtained and called "atroscine", and to save the name "hyoscine" to indicate levo-scopolamine. Since the true composition of this alkaloid, as now recognized in all Pharmacopoeias, is associated with the name given it by Schmidt, it would seem but proper also to use that name as its official title, and this has been done in the German and United States Pharmacopoeias, "hyoscine" being given as a synonym. The reverse is true of the British Pharmacopoeia (9). In the U.S.P. VIII. (94) both Hyoscine Hydrobromide and Scopolamine Hydrobromide were listed under separate monographs and neither one was required to be levorotatory. The fallacy of this situation was recognized and condemned by Emmert (27), Hesse (44, 45), Merck (78), Kunz-Krause (64), and here in America by DuMez (20). Largely through the efforts of DuMez in 1914, this situation was clarified in the U.S.P. IX (95) which became official two years later. DuMez criticized the official tests for identity and purity and presented evidence of the greater activity of the levorotatory compound official under the name of "scopolamine" in the German Pharmacopoeia. As a result, "scopolamine" was adopted as the official title in the U.S.P. IX and "hyoscine" was listed as a synonym.

It has been stated that there is a difference in the therapeutic effects of scopolamine, depending upon its botanical source (73), and this is perhaps the chief reason for the reluctance of some individuals to use the words "scopolamine" and "hyoscine" interchangeably. Quoting, for example, from the latest edition (4th, edition—1937) of "Principles of Pharmacy" by Arny and Fischelis (4):

Hyoscine—This alkaloid has the formula C_{17} H_{21} N O_4 and is isomeric with scopolamine. — The present Pharmacopoeia takes the view that it is the same as scopolamine and therefore includes the formerly official Hyoscine Hydrobromide in the monograph on Scopolamine Hydrobromide.

On the other hand, Sollmann (120), in his "Manual of Pharmacology" (5th edition—1937), states that:

It was formerly stated that there are specific differences in the effects according to the origin of the alkaloids, and that "hyoscine" derived from Hyoscyamus is therapeutically superior to the "scopolamine" of Scopola. No such difference can exist if the pure alkaloids are employed, for these are identical, whatever their source.

The bulk of the scopolamine used in the United States is imported, and its use in clinical medicine has been increasing steadily since its introduction many years ago. The demand for scopolamine as a pre-anesthetic in surgery and childbirth, its use in ophthalmology, the increase in the employment of scopolamine-morphine narcosis, its use as a treatment in post-encephalitic Parkin-

sonism and its remarkable efficacy in the prevention of motion (air and sea) sickness, have increased steadily in recent years. These and other equally important medical applications of this valuable material were investigated by Carmichael and Green (12), Sollmann (120), Jacobson and Epplen (42), van Leeuwen and Szent-Gyorgyi (71), Webster (131), Hill (48), Krebs (60), Kreitmair (61), Neuwahl (89), Waters (130) and others.

Experimental

Analysis. Carefully cleaned and dried *Datura innoxia* leaves meeting the Pharmacopoeial stem requirements for Stramonium leaves were milled and passed through a number 20 sieve. The coarse sifted powder was uniformly mixed with the fine, and representative samples were taken for the analysis. In the assays which followed, the alkaloidal yield was based upon the molecular weight of scopolamine rather than atropine, the latter being the one normally used in the Pharmacopoeial standardization of the mydriatic drugs. This was done because Hester and Davy had demonstrated that the only alkaloid present in *D. innoxia* leaves is levoscopolamine. The method of analysis used was a modification of the U.S.P. XI. method for Stramonium as follows:

Ten grams of drug were accurately weighed and placed in an extraction thimble which was inserted into a standard Sohxlet extractor. This was moistened with a mixture of 15 cc. stronger ammonia water T.S., 15 cc. ethyl alcohol 95%, and 40 cc. of ethyl ether. More ether may be added if necessary to maintain a layer of liquid over the drug. This was allowed to macerate over night and was then extracted for five hours on a water bath, using ether as the solvent.

The ether solution was concentrated by evaporation to approximately 50 cc. and filtered into a separator. The filter paper was rinsed twice with small portions of ether. Normal sulfuric acid was added until the mixture was acid to litmus, and an excess was added for extraction purposes. The ether solution was extracted four times with 1 N. sulfuric acid, using approximately 20 cc. each time. After the fourth shakeout the ether was tested with Mayer's Reagent for the presence of alkaloid. Usually after four or five shakeouts the ether gave a negative test and was then washed once with 20 cc. of distilled water which was added to the combined acid extracts.

The acid solution was made alkaline with ammonia and extracted in the same manner with four or five successive portions of chloroform until the alkaloidal extraction was completed and the aqueous layer gave a negative test with Mayer's Reagent.

The combined chloroform extract was evaporated to dryness on a water bath until the odor of chloroform was no longer perceptible. It was then heated for an additional half hour, chloroform was added to redissolve the chlorophyll and it was again heated to dryness. It was then allowed to heat for another half hour and the entire process repeated twice more, for a total of four times to insure complete elimination of ammonia soaps.

The alkaloidal residue was taken up in chloroform, and 25 cc. of N/50 sulfuric acid were added. The chloroform was evaporated, the flask being shaken at intervals during the process. The solution was cooled, and the excess acid was titrated with N/50 sodium hydroxide solution using methyl red as indicator.

1 cc. N/50 acid is equivalent to 0.00606 gm. scopolamine or 0.00578 gm. of the total alkaloids of the Hyoscyamus type.

Assays on different samples of the 1939 crop of *Datura innoxia* by the above method showed the following percentages of scopolamine present:

(1) 0.52 (2) 0.545 (3) 0.62
(4) 0.54 (5) 0.566

These figures confirm the results of Hester and Davy. An average of their 19 assay results showed the drug to contain 0.51% scopolamine. Their results ranged from 0.394% to 0.713%, but they used seven different assay method modifications, and that undoubtedly accounts for the variations they obtained.

In order to determine whether or not the entire plant could be utilized in the commercial extraction of scopolamine, the following analytical work was carried out. The method of assay used is the same as that given above. The drug used was, however, from the 1940 crop. Similar studies have been made on *Datura Stramonium* by Clark (16), Eby, Scholl and Phillips (26), Feldhaus (29), Jenkins (53), Koch (58) and Kuntz (62, 63) and on *Datura Metel* by Schmidt (113) and Kircher (57).

Part used:	Alkaloid %	Water %	Total Ash %	Acid insol. Ash %
Leaves	0.520	7.5	15.6	2.30
Calices	1.080	8.3	12.2	1.50
Stems	0.300	7.5	10.7	3.06
Roots	0.394	6.6	15.9	5.20
Fruits	0.770	7.5	11.0	0.40
Capsules	0.334	7.5	13.2	5.35
Seeds	0.436	4.2	10.2	0.32

The alkaloidal residues from these assays were saved for qualitative microscopic identification of the alkaloid through the aurichloride. In each instance the solution after titration was made alkaline with ammonia and extracted with ether. The ether was driven off on a water bath, the residue dissolved in dilute hydrochloric acid (5%), and a solution of gold chloride was added. This was then warmed on a water bath to aid in the formation of the double salt and chilled to crystallize out the aurichlorides. The supernatent liquid was decanted in each instance, and the crystals were examined under the microscope and compared with a similarly treated sample of Scopolamine Hydrobromide U.S.P. purchased from Merck & Co., Inc. This was packaged in a two ounce amber bottle, the label of which bore the printed number BS 39 74 1 and was stamped with Control Number 32559.

This is the method for identification of the mydriatic alkaloids suggested by Glycart (36) and adopted by the Association of Official Agricultural Chemists in 1935. Additional methods for the specific identification of the solanaceous alkaloids have been developed by Fulton (32), Gerrard (35), Nelson and Leonard (88), Oliverio (90), Wasicky (128) and others (70), but it was felt that Glycart's method was the simplest and best, so it was here used.

The crystalline form of the aurichloride indicates conclusively that scopolamine alone is present in *Datura innoxia*. As far as could be determined, no other crystal forms were present, indicating the absence of any appreciable amounts of atropine or hyoscyamine.

Scopolamine. For the purpose of making a complete examination of the alkaloid in *D. innoxia*, a series of batches of drug weighing from 2 to 10 kilograms were extracted, using various solvents and methods of handling. It is not necessary to go into all of the details of the preliminary extraction experiments, but it is desirable to mention a few of the obstacles which were encountered and which gave considerable difficulty in the extraction and isolation of the pure alkaloid from the drug.

Ethyl alcohol 95%, ethyl alcohol denatured with acetone (S.D. #23 A), isopropyl alcohol, and a 50% ethyl alcohol menstrua were tried in the initial experiments. All of these menstrua possess certain advantages as well as disadvantages for this purpose. Rapid penetration and probably fairly complete extraction of the drug was obtained with these solvents; the principal objection to their use, however, lies in the fact that *Datura innoxia* is exceedingly rich in chlorophyll, other plant pigments, resins and other waxy or fatty alcohol-

soluble materials of as yet undetermined constitution. These substances, once extracted, are difficult to eliminate and cause troublesome emulsions which had best be avoided if possible.

Accordingly it was attempted to extract the drug with hot acidulated water in accordance with the suggestion of Brill (7) as a result of his experiments with *Datura alba*, a drug similar to *Datura innoxia* in having a fairly high scopolamine content. Sulfuric, hydrochloric and acetic acids in various concentrations were employed. Sulfuric acid, being non-volatile, is objectionable because its concentration increases to an extent which will certainly racemize and probably decompose the alkaloid in the concentration of the dilute aqueous percolate in vacuo. Hydrochloric acid is similarly objectionable, even though it is volatile, since it will tend to remain in the concentrate and form a fixed boiling point solution of too high a concentration for the safe preservation of the alkaloid in the vacuum reduction process. Acetic acid was therefore found to be best for this purpose, and concentrations of from one to five percent were tried with some degree of success.

The use of hydroquinone as an antioxidant in the percolation process was tried and abandoned. It apparently is not needed and it complicates the extraction and purification procedures. Due to the phenolic properties of its decomposition products, it reacts with the iron in the percolators and causes the extract to turn red. It also clouds the Mayer's Reagent test for completeness of extraction of the alkaloid.

It was found that the use of some alcohol in the initial maceration and flooding of the drug was helpful because a better penetration with more complete extraction of the alkaloid from the plant cells was thus obtained (11). It is true that this alcohol will extract some of the objectionable alcohol-soluble, water-insoluble materials in the first percolation, but these can be removed almost completely by diluting the first percolate with subsequent aqueous percolates. This will lower the alcohol concentration, and the water-insoluble substances will precipitate out of solution as a dark green tarry mass. The supernatent liquid contains the soluble scopolamine acetate and can readily be decanted and reduced in vacuo.

The use of glass-lined or stainless steel equipment is necessary when using acetic acid, and contact with copper should be avoided.

The procedure successfully employed for the extraction of scopolamine alkaloid from *D. innoxia* is as follows:

A ten kilogram batch of ground drug was moistened with a menstruum of 48% isopropyl alcohol, 48% water and 4% glacial acetic acid (pH approx. 5.0). The drug was allowed to swell for four hours and was then packed in a cylindrical steel percolator, flooded with this same menstruum and macerated for 24 hours. Percolation was permitted to proceed at a fairly rapid rate. The initial percolate was drained off and set aside. The percolation was continued until the drug was completely exhausted, using a solution of 2% glacial acetic acid in hot water (pH approx. 5.5) as menstruum. The first percolate was diluted with four times its volume of secondary aqueous percolate to precipitate out the alcohol-soluble, water-insoluble extractive, allowed to set for 24 hours, decanted, and it, as well as all subsequent percolates, were made alkaline with ammonia and reduced to a semi-solid extract in vacuo at a temperature of 55° to 60° C. This extract was refluxed with 99% isopropyl alcohol for eight hours to extract the alkaloid from the tarry residue which is almost completely insoluble in this solvent. The alcohol was drained off and set aside and the refluxing operation was repeated a second and third time in the same manner with equal volumes of isopropyl al-

cohol. The three portions of isopropyl alcohol were combined, and the tarry residue was tested for alkaloids by dissolving a small portion of it in water, acidifying and adding Mayer's Reagent. It was not necessary to reflux the residue a fourth time.

The combined isopropyl alcohol solution was made definitely alkaline with ammonia, filtered and reduced to a syrupy consistency in vacuo. The isopropyl alcohol was recovered. The alkaloidal base was taken up in ether, filtered, the ether recovered by distillation, and the residue dissolved in 5% acetic acid. The acetic acid solution was made alkaline with potassium carbonate and shaken out four times with ether. A mechanical shaker holding eight separatory funnels was employed. This machine vigorously shakes the funnels 100 to 120 times per minute, and the shaker was run for approximately one hour on the first two shakeouts and one-half hour each on the last two shakeouts.

The combined ether extract was washed once with distilled water and the ether recovered by distillation, leaving behind a thick, amber, viscous residue which is scopolamine alkaloid. Attempts to crystallize the alkaloid from ether, absolute alcohol and a mixture of the two were unsuccessful.

The specific rotation (a) $\frac{20}{D}$ in absolute alcohol was found to be $-18.75°$ (See chart p. 448 for comparison with figures recorded in the literature).

Scopolamine Salts. Scopolamine picrate, aurichloride, hydrochloride and hydrobromide were prepared from the scopolamine alkaloid obtained from *D. innoxia*. The first three were prepared to aid in establishing the specific identity of the alkaloid, and the last one, namely the hydrobromide, was prepared because that is virtually the only form in which levo-scopolamine is used in medicine, and it is the form official in the United States Pharmacopoeia (97). The following methods of preparation were employed:

Scopolamine Picrate—Picric acid dissolved in 95% ethyl alcohol was added to an alcoholic solution of scopolamine alkaloid, and the mixture was warmed on a water bath. This was agitated with a larger volume of water containing a few drops of hydrochloric acid. The precipitate was filtered off and washed first with ether and then once with benzene to remove excess picric acid. The residue on the filter paper was recrystallized from boiling water, and the melting point of the resulting needles after drying was found to be 186.5°–188° C. (See chart p. 449 for comparison).

Scopolamine Aurichloride — Scopolamine alkaloid was dissolved in dilute hydrochloric acid, gold chloride solution was added, the crystalline precipitate separated from the mother-liquor by filtration and recrystallized from boiling water. The melting point of the crystals, after drying, was found to be 197°–199° (See chart p. 449 for comparison).

Scopolamine Hydrochloride—Scopolamine alkaloid was dissolved in ethyl alcohol containing a small amount of concentrated hydrochloric acid, and the alcohol was driven off on a water bath. The residue was recrystallized from alcohol by spontaneous evaporation. The colorless rhombic crystals, after drying, had a melting point of 190°–192° C. (See chart p. 449 for comparison).

Scopolamine Hydrobromide—This is by far the most difficult salt to prepare, and one can get little help from the literature on the subject. It is of paramount importance, however, because it is the form universally used in medicine and is official in most Pharmacopoeias.

Schmidt's method for the preparation of the hydrobromide from the alkaloidal base purportedly consisted of adding aqueous hydrobromic acid and permitting the salt to crystallize out on long standing. His method did not meet with success in this experiment, since

the hydrobromide refused to crystallize, and attempts to promote crystallization by storage in a vacuum desiccator, seeding, evaporation of solvent by heating, directing a stream of compressed air on the surface of the liquid, and freezing, were of no avail.

A procedure similar to that employed by Chemnitius proved to be more successful and involved the preparation and use of alcoholic hydrobromic acid which was made as follows:

Five parts of red phosphorus, one part of potassium bromide, and ten parts of aqueous hydrobromic acid 47% were placed in a suitable generator flask. Bromine was added dropwise in a steady stream to this mixture, and the resulting hydrogen bromide gas was passed through a drying tube containing red phosphorus to remove any free bromine, through tubes of calcium chloride and Drierite (calcium sulfate) to remove water, and then bubbled through absolute alcohol in a container surrounded by ice. Glass wool instead of cotton was used to hold the materials in the drying tubes. A trap was inserted in the line between the alcohol flask and the last drying tube to catch the liquid in case the reaction in the generator should stop and create a negative pressure in the system. A solution of hydrobromic acid containing 20% hydrogen bromide in absolute alcohol was prepared in this manner.

Scopolamine alkaloid was dissolved in a small volume of absolute alcohol, and to this was added sufficient alcoholic hydrobromic acid until a slightly acid reaction to litmus was obtained. Ether was added up to the point where clouding began to occur, and the solution was then seeded and placed in a refrigerator for three days. Scopolamine hydrobromide crystallized out very slowly. The mother-liquor was decanted and set aside for recovery of the alkaloid as basic scopolamine and subsequent repetition of the procedure just outlined.

The scopolamine hydrobromide was redissolved in alcohol, decolorized with animal charcoal (54) and recrystallized. A portion of the material, after being dried, had a melting point of 195° C. and a specific rotation (a) $\frac{25}{D}$ in water of −24.24° (see charts on p. 28 & 29).

A sample of the purified scopolamine hydrobromide meets the requirements for identity and purity of the U.S.P. XI. Constants obtained for levo-scopolamine isolated from *D. innoxia* and compared with those reported in the literature are summarized in the following charts on this and the next page:

SPECIFIC ROTATION

Results	Alkaloid*	Hydrobromide**
	−18.75	−24.24
B. P.—1932 (9)		−24 to −26
Evers (28)		−25.9
Fuller (31)	−13 to −18	−25.45
Henry (40)	−18	−25.93
Hester & Davy (47)	−16.5	
Landolt (68)	−13.7	−22.5
Merck Index (77)		−24 to −27
U. S. P. XI (97)		−22 to −25.75

* in alcohol ** in water

Phytochemical Notes

Little work was done on any of the constituents of the plant other than levo-scopolamine. It was, however, noted that the seeds are very high in fixed oil content. This is to be expected, since the seeds of *Datura Stramonium* contain approximately 25% fixed oil, as investigated by Holde (50), Meyer and Beer (79). According to Clark (17), the principal constituent of this oil is daturic acid (margaric acid?).

The dark brown tarry residue from the acetic acid extraction of the drug was found to contain reducing sugars, oxalates and nitrates, but no tannin.

An alcohol extract of the leaves, when reduced in vacuo, freed from alkaloid and extracted with petroleum ether, yielded a small amount of a colorless, non-volatile fluid having the properties of a fixed oil.

The leaves are very rich in chlorophyll and carotene, and a preliminary experi-

MELTING POINTS

Results	Picrate 186.5–188	Auri-Chloride 197–199	Hydro-Chloride 190–192	Hydro-Bromide 195
Allen (1)		198–200		
Aut. & Warren (5)		210–214		
B.P.—1939(9)				194–196
Carr & Reynolds (13)	180–181	198–200	200	
Evers (28)	187.5–188.5	208–209		193–194
Fuller (31)	187–188	198–199		
Henry (40)	191–192	208–209		193–194
Hesse (41)		198		
Hester & Davy (47)	188	199		
Kircher (57)		208–209		
Merck Index (77)				194–197
Prescott (100)		198		
Schmidt (111)		212–214		
U. S. P. XI (97)				190–192
Von Oettingen (127)			193–194	

ment showed that these two vegetable pigments may be extracted with 85% acetone after the alkaloid has been removed from the drug. When this acetone solution is refluxed for eight hours or more with barium hydroxide, the chlorophyll is precipitated in the form of a green sludge, leaving the carotene in solution. This can be decanted, filtered, reduced to a semi-solid fatty consistency and redissolved in petroleum ether for further purification. From this the beta-carotene can be crystallized after the petroleum ether has been washed with 85% methyl alcohol to remove the xanthophylls.

The chlorophyll can in turn be recovered from the barium hydroxide sludge by treatment with acid. It can then again be taken up in acetone, purified and concentrated.

Summary

The Daturas have been used medicinally as well as in religious ceremonies in every land by every people from prehistoric times to the present. They are mentioned in the literature of the Greeks, Arabs, Persians, Hindus, Chinese, Japanese, Aztecs and other ancient peoples. *Datura Metel* L., the species believed to be the source of the metel-nut, Nux Methal, and Hippomanes of the ancients, is very common in India. This plant is often confused with a closely related species, *Datura innoxia* Miller, indigenous in Mexico and tropical America but introduced into Europe and Asia.

Datura innoxia was first described by Philip Miller in the 8th edition of his "Gardener's Dictionary" in 1768. Several botanists have since confused its identity with *D. Metel, D. meteloides, D. fastuosa* and other species. The synonymy of the Daturas was clarified by the work of Safford in the United States (1921) and Timmerman in England (1927).

D. innoxia Miller belongs to the family Solanaceae. It is an annual plant about three or four feet high, divided into several strong branches. The leaves are oblong, heart-shaped. The stems, branches and leaves are covered with soft hairs. The large white erect flowers are born in the axils of the stems. The fruit is ovoid, covered with innocuous spines and opening into four chambers, full of brown seeds. Like most other Daturas, *D. innoxia* has a rank, nauseating, narcotic odor. The chief distinguishing botanical features of the plant are its dense pubescence, the typical solanaceous stomata and the characteristic trichomes on both surfaces of its leaves.

D. innoxia can readily be cultivated in a rich clay loam and grows best in the sunshine. The seeds may require treatment such as alternate freezing and

thawing to aid in germination. They may be sown in early spring, and the entire plants should be harvested in August at the time of flowering to obtain a maximum alkaloidal yield. They should then be dried at a temperature of about 60° C. and ground in a Mead mill to a #20 mesh. The drug is then ready for pharmaceutical extraction.

The usage of the terms "scopolamine" and "hyoscine" has caused much confusion and controversy. In Germany the names "levo-" and "inactive scopolamine" are employed. In England the term "hyoscine" is used to indicate the levo-base. In the U.S.P. VIII. both Hyoscine Hydrobromide and Scopolamine Hydrobromide were official under separate monographs. Preference is now given to "levo-scopolamine" as the proper name and is recognized in the U.S.P. XI., "hyoscine" being given as a synonym.

Opinions differ greatly as to the proper method of assay of solanaceous drugs, particularly as regards the solvent and treatment of the alkaloidal residue in the chemical analysis. The present U.S.P. XI. method for the assay of Stramonium, with some modifications, was found to be most suitable.

The plant used in these experiments was grown in the Medicinal Plant Garden of the Squire Valleevue of Western Reserve University from seeds submitted by Mr. A. F. Sievers of the Bureau of Plant Industry in 1927. Assays of the leaves (0.52%), stems (0.30%), seeds (0.436%), roots (0.394%), fruits (0.77%) and capsules (0.668%) indicate clearly that the entire plant may be used to advantage as a source of scopolamine.

Levo-scopolamine was isolated and identified as the only alkaloid present in *D. innoxia* Miller. A quantity of the alkaloid was extracted from the drug, and some of its compounds were prepared to confirm its specific identity. The optical rotation of the alkaloid and its hydrobromide as well as the crystal forms and melting points of the picrate, aurichloride, hydrochloride and hydrobromide conclusively prove the alkaloid to be levo-scopolamine.

A review of the literature on the industrial production of levo-scopolamine from various solanaceous plants discloses several lengthy and costly procedures developed for this purpose in Germany, the principal commercial source of the alkaloid. No method for obtaining scopolamine from *D. innoxia* was described, and, in fact, the only article of a chemical nature on this plant was the one published by Hester and Davy in 1933, describing the study of the alkaloids of *D. innoxia* raised in the Medicinal Plant Garden of Western Reserve University.

A practical industrial method of preparing levo-scopolamine from *D. innoxia* Miller was developed and several 10-kilogram lots of the drug were extracted as follows:

The ground drug was packed in a cylindrical steel percolator and macerated for 24 hours with a menstruum of 48% isopropyl alcohol, 48% water and 4% acetic acid. A 2% solution of acetic acid was used as additional menstruum, and the drug was extracted with that until all the alkaloid had been removed. This was reduced to a semi-solid extract in vacuo, and the alkaloid was washed out of this by refluxing with isopropyl alcohol and ammonia. The alcohol was recovered, and the residue from the alcoholic solution was dissolved in ether, filtered, the ether recovered and the alkaloid taken up in 5% acetic acid. This was made alkaline with potassium carbonate and shaken out with ether. The ether extract, when evaporated, left behind the pure scopolamine base which was a heavy amber liquid having a specific rotation of $-18.75°$.

This can be converted to any of its salts, the official salt being the hydrobromide which can be made by neutralizing

scopolamine alkaloid with alcoholic hydrobromic acid and permitting it to crystallize out upon prolonged standing in a vacuum dessicator in a cool place. The salt was found to have a melting point of 195° C. and a specific rotation of −24.24°.

The picrate (m.p. 186.5–188°), the aurichloride (m.p. 197–199°) and the hydrochloride (m.p. 190–192°) were also prepared for purposes of identification. The physical constants mentioned above for the alkaloid and its salts agree with those found by other investigators and recorded in the literature.

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